

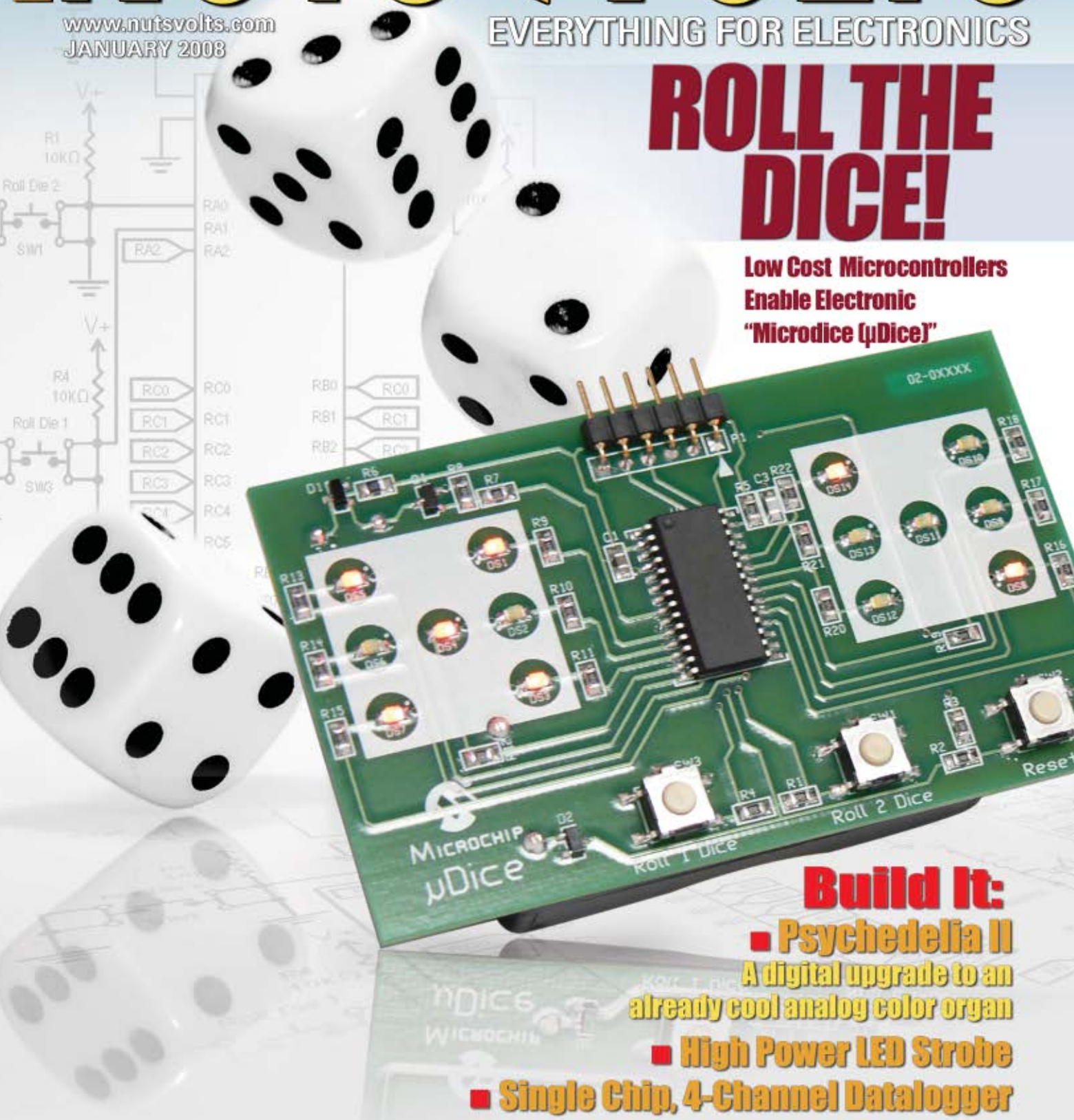
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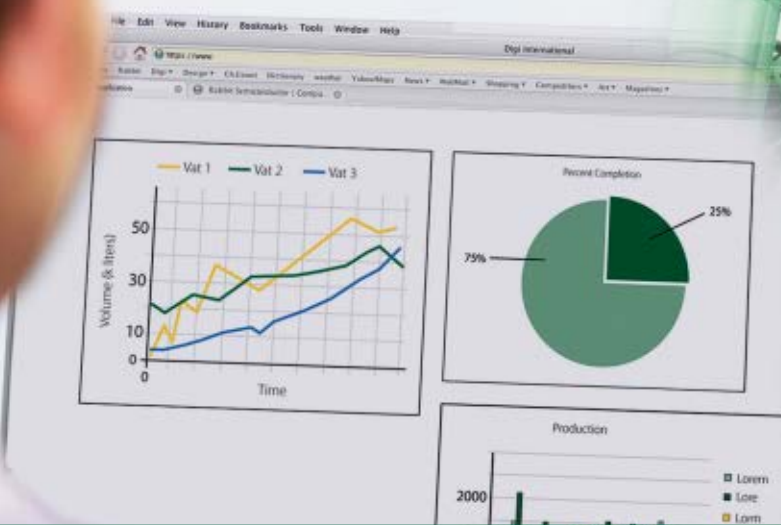
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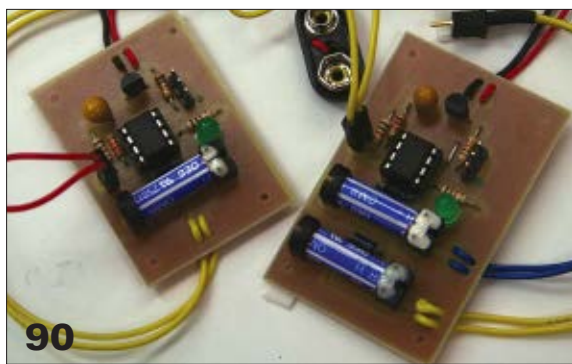
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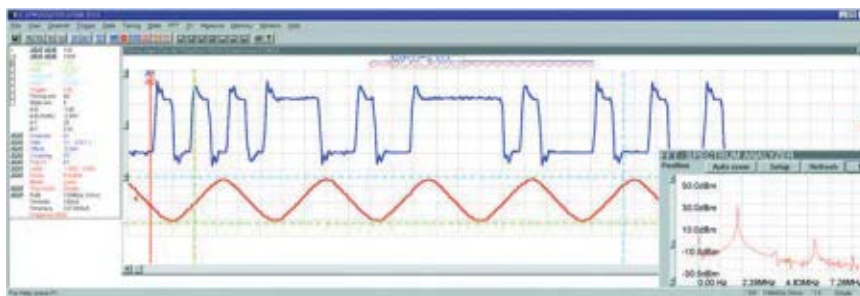


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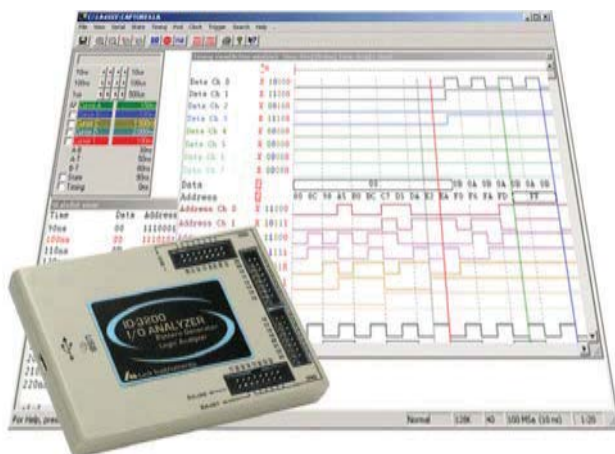
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# DEVELOPING PERSPECTIVES

by Bryan Bergeron, Editor



A fundamental application of electronics is transformation — from power supplies that transform AC to DC to microprocessors that transform binary code to text, graphics, and sound. While transformations at many levels may be critical to

the function of a device or application, it's the high-level sensory transformations that hold the greatest potential to change the world. I'm talking about the high-level transformation of sensory experiences, illustrated at one level by Craig Lindley's article on a digital color organ in this issue.

Transforming sensory data from one form to another has both entertainment and pragmatic value. For example, a color organ that transforms sound amplitude and/or frequency to colors can serve as an entertainment device and as an aid to configuring the graphic equalizer front-end of a stereo system. More significantly, sensory transformation may be used to augment normal senses and to supplement damaged sense organs.

Consider the matrix of potential sensory transformation in Table 1 as an aid to exploring how sensory transformation can be applied to correct a sensory deficient or to augment a person's normal abilities. The matrix is an over-simplification to the extent that each sense may take on several variables or may be modulated. For example, hearing may involve the perception of pitch, amplitude, and direction, and vision can encompass color, intensity, movement, and size.

A prominent feature of the transformation matrix is that it is sparse — with a few prominent exceptions, sensory transformation is largely unexploited. There is the familiar light organ that transforms sound to either fluctuations in LED bar graphs or dynamic displays in Apple iTunes or Microsoft Media Player. Computer-controlled haptics interfaces provide virtual screen objects with realistic mass, elasticity, and momentum. Flight attitude indicators supplement a pilot's vestibular system by showing attitude and an artificial horizon. As suggested by the matrix, useful transformations can be performed within a given sense, such as augmenting hearing by transforming high frequency audio signals into signals within the normal range of human hearing, or transforming infrared light to visible light.

One reason for the relatively few sensory transformations in everyday use is the lack of appropriate sensors and transducers. My latest focus in esoteric sensors is on the various light sensors from Texas Advanced Opto-Electronic Solutions (TAOS, [www.taosinc.com](http://www.taosinc.com)) and Texas Instruments ([www.ti.com](http://www.ti.com)), including light-to-voltage and light-to-frequency chips and a variety of color sensors. Light-to-frequency chips convert light intensity to a microcontroller-compatible pulse train with a frequency proportional to light intensity. With a microprocessor on the sensor output, light intensity can be easily converted to sound, color shift, smell, or pressure, given an appropriate transducer.

Another reason for the lack of sensory transformations is the difficulty in determining what is practical and useful in everyday life. One area of active research and development is medicine. Consider a diabetic with the inability to detect pain in his feet because of the loss of sensation (diabetic neuropathy). Because of this loss of sensation, diabetics often neglect sores, cuts, and bruises on their feet, resulting in infections and, in some cases, gangrene. However, pressure sensors in the shoes or shoe inserts of a diabetic could transform a sudden pressure gradient — ordinarily perceived as pain — into a prick or modest electric shock on the leg, an audible alarm, a flashing light, or even an odor.

Study the matrix in Table 1, devise your own applications, and then dive in with the appropriate sensors, transducers, and microcontrollers. And don't be constrained by the matrix — many useful assistive devices add new senses. For example, a talking compass or GPS provides direction and location information that a normal person can't determine from his innate senses.

If you'd like a ready source of inspiration, google "synesthesia." People with this condition experience sensations seemingly unrelated to the initial stimulus. For example, a particular sound may evoke the visualization of a color — akin to a built-in light organ. **NV**

**Table 1. Sensory Transformation Matrix showing common transformations.**

Vibration Pressure	Pressure	Hearing Sound Localization	Vision
Proprioception			Flight Indicator Flight Attitude Indicator Light Organ
Balance			
Hearing		Frequency Shift	
Taste Smell Vision	Haptics		Frequency Shift (IR Camera) IR Camera, No-contact Thermometer
Temperature			
Pain			

*Additional headers not listed at the top also include: Proprioception, Taste, Smell, Temperature, and Pain.*

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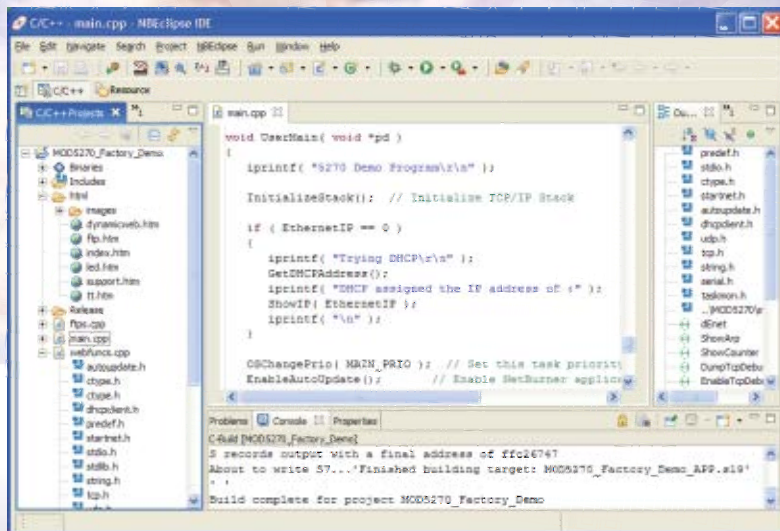
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# READER FEEDBACK

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## MIM's THE WORD

Paul Verhage's Near Space column on an "LED Based Photometer" is a very interesting balloon-based project. As Paul explained in his column, LEDs can function as wavelength-selective photodiodes. They exhibit far less drift than silicon photodiodes that employ optical interference filters to provide wavelength tuning. A limitation of using LEDs, however, is that they are generally much more temperature sensitive than silicon photodiodes, as Paul discovered during one of his near space missions.

It's possible to devise a correction function for an LED photometer that relies on a thermistor or other temperature sensor installed very close to the LED. While there are ways to do this electronically, I prefer a straightforward algorithm and a spreadsheet.

As for wavelength sensitivity of LEDs, blue LEDs I've tested tend to respond best to a narrow spike at or near 376 nm and a wide shoulder extending out to perhaps 450 nm. Typical green LEDs respond at about 525 nm and typical red LEDs at 620 nm. The spectral bandpass of green and red LEDs is around 20-25 nm at the half power points. All these numbers are closely related to the device chemistry.

I edit *The Citizen Scientist* ([www.sas.org/tcs](http://www.sas.org/tcs)) for the Society for Amateur Scientists, and I just checked and found that we have mentioned *Nuts & Volts* — my favorite electronics magazine — only seven times in recent years. Based on Paul's columns and various other science projects, it appears that we need to do a better job of informing our readers about the latest science-related *Nuts & Volts* projects.

**Forrest M. Mims III**

## NEW LIGHT ON COMMUNICATIONS

I was delighted to see the Near Space article by Paul Verhage on the LED based photometer. It not only was a neat solution to a problem that can be costly to solve, but brought back memories and

connections with several items, and a famous innovator, from years ago. As a former student in the early 1970s at Drexel University, I was pleased to see the school mentioned as a place to go for a sensing system design. That Forest Mims suggested it reminded me of another connection with this application, to wit: I began experimenting with LEDs in the very early 1970s.

At that time, I was an evening division student at Drexel and in the daytime experimented with light transmission using lenses and the new optical fiber from G.E. that Poly Paks sold. I wanted to send audio from my radio to another part of the house to where I could listen without disturbing my sisters sleep with laughter while listening to late night comedy. I eventually tried using an LED as a receiver after getting poor results with sending audio modulation to a phototransistor. The circuit worked but the cable could pick up light signals from various sources (bare fiber). I decided to try using FM modulation of an RF source and the LED as a transmitter. The generator was of the NE560 family and the receiver an NE561 I had tried for AM and short wave. The low cost detectors didn't have the bandwidth to handle the signal I wanted to use (455 kHz), but I knew from the LED spec sheets they could easily do this. I tried it and it worked, but I was not able to use it. Oddly enough, I heard later that Mr. Mims and Bell Labs had a patent fight over the use of LEDs as receivers in optical systems of some kind.

Depending on your application, this shift in how a part is used can be the best solution to a problem. I have used LEDs as narrow band sensors for some time, from "mid" infra red through blue-violet, but only occasionally for communications. I should point out that at least one company makes devices as narrow band detectors in the near infrared to match their emitters via using the same semiconductors. This requires very good process control in practice. Thank you for the excellent article(s).

**Earl Bennett**

*Response: Thanks for the reply, I appreciate it when readers comment*

*Continued on page 97*

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### FOUNDER/ASSOCIATE PUBLISHER

Jack Lemieux

### PUBLISHER

Larry Lemieux

[publisher@nutsvolts.com](mailto:publisher@nutsvolts.com)

### ASSOCIATE PUBLISHER/ VP OF SALES/MARKETING

Robin Lemieux

[display@nutsvolts.com](mailto:display@nutsvolts.com)

### EDITOR

Bryan Bergeron

[techedit-nutsvolts@yahoo.com](mailto:techedit-nutsvolts@yahoo.com)

### CONTRIBUTING EDITORS

Chuck Hellebuyck

Jeff Eckert

Fred Eady

Jon Williams

Paul Verhage

Marc McComb

Clifford Chipman

Marvin Mallon

Russ Kincaid

Vern Graner

Gerard Fonte

Craig Lindley

Fernando Garcia

Dan Gravatt

### CIRCULATION DIRECTOR

Tracy Kerley

[subscribe@nutsvolts.com](mailto:subscribe@nutsvolts.com)

### SHOW COORDINATOR

Audrey Lemieux

### MARKETING COORDINATOR WEBSTORE

Brian Kirkpatrick

[sales@nutsvolts.com](mailto:sales@nutsvolts.com)

### WEB CONTENT

Michael Kaudze

[website@nutsvolts.com](mailto:website@nutsvolts.com)

### PRODUCTION/GRAPHICS

Shannon Lemieux

Joe Keungmanivong

### ADMINISTRATIVE ASSISTANT

Debbie Stauffacher

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■ BY JEFF ECKERT

## ADVANCED TECHNOLOGY

### WORLD'S SMALLEST RADIO PLAYS CLAPTON

PHOTO COURTESY OF ZETTL RESEARCH GROUP, LAWRENCE BERKELEY NATIONAL LABORATORY, AND UNIVERSITY OF CALIFORNIA AT BERKELEY.



■ Transmission electron microscope image showing a carbon nanotube radio protruding from an electrode ("waves" added for effect).

If you think your iPod nano is compact, consider a radio recently developed at the University of California, Berkeley ([www.berkeley.edu](http://www.berkeley.edu)). Said to be the smallest radio ever built, the nanoradio, which presently operates as a receiver but could work as a transmitter as well, is a single carbon nanotube that operates as a combined antenna, tuner, amplifier, and AM/FM demodulator. (A nanotube, by the way, is a rolled sheet of interlocked carbon atoms that form a tube that is extremely strong and also exhibits some peculiar electronic properties. This one is about 10 nm in diameter and less than 1 μm long, making it about 1/10,000 as thick as a human hair.)

The operation is fairly straightforward. When radio waves strike the nanotube, it begins to vibrate. You then apply an electric field, which forces electrons to be emitted from its tip. This current is used to detect the vibrations and thus turn the radio waves back into sound.

In one of the early experiments, team leader Alex Zettl, UC Berkeley

professor of physics, and his team successfully transmitted such works as "Layla" (Derek & the Dominos), "Good Vibrations" (Beach Boys), and "Largo" (from the Handel opera "Xerxes") across a room.

To see and hear for yourself, drop into the Zettl group page at [socrates.berkeley.edu/~argon/nanoradio/radio.html](http://socrates.berkeley.edu/~argon/nanoradio/radio.html). According to the prof, the nanoradio may prove useful in a variety of applications "from cell phones to microscopic devices that sense the environment and relay information via radio signals ... The nanotube radio may lead to radical new applications, such as radio-controlled devices small enough to exist in a human's bloodstream."

### NANOGENERATOR DEMONSTRATED

The UC Berkeley device described above is powered by a battery, but

perhaps its developers should take note of the nanogenerator recently revealed by researchers at the University of Illinois ([www.uillinois.edu](http://www.uillinois.edu)). Because even the smallest batteries are impractically large for driving micro and nanoscale devices, Prof. Min-Feng Yu has been working on ways of harvesting power from nanoscale mechanical energy.

Toward that end, he and some grad students have created a nanowire that generates a voltage when mechanically deformed. The nanowire is a single crystal of barium titanate (a piezoelectric material used in ceramic capacitors, microphones, and other transducers), approximately 280 nm in diameter and 15 μm long.

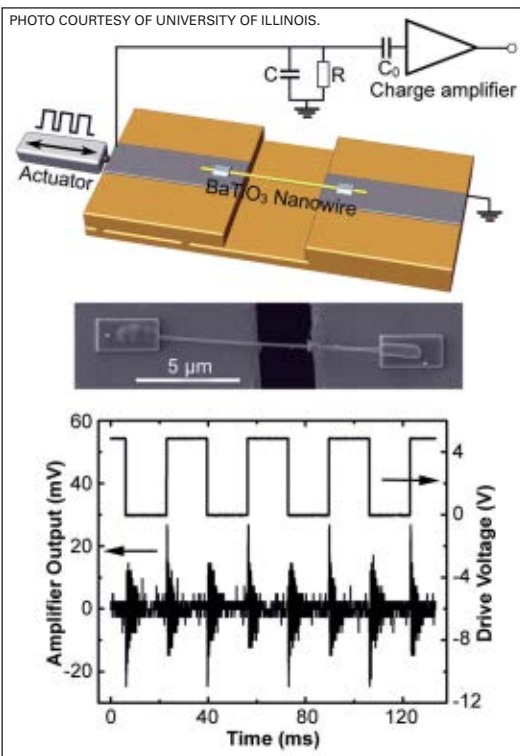
The wire was placed across a 3 m gap on a test rig and exposed to induced mechanical vibrations. The result was an electrical energy output of 0.3 attojoules (less than a quintillionth of a joule) per vibrational cycle, which is very interesting.

However, just for perspective, to run a 100W lightbulb for an hour, you would need about  $3.6 \times 10^{23}$  of them, so we're not talking hydroelectric dams here. But with further development, something useful may emerge.

### FUEL CELL BREAKTHROUGH

On a more immediately practical level is a breakthrough in fuel cell technology at the University of Houston ([www.uh.edu](http://www.uh.edu)). One of the biggest hurdles in building economical fuel cells to drive electric cars of the

PHOTO COURTESY OF UNIVERSITY OF ILLINOIS.



■ Top: Schematic setup for piezoelectric charge detection from barium-titanate nanowire. Bottom: Scanning electron microscope image of the wire.



future has been the cost of the catalyst that facilitates the reaction of hydrogen and oxygen. The most common one is platinum, which in November hit a high of about \$1,500 per ounce. At that level, powering a small (100 kW) vehicle would run between \$2,300 and \$3,700 for just the catalyst.

However, Professor Peter Strasser, of UH's Cullen College of Engineering, has reportedly developed a low platinum alloy that produces four to six times more reaction for the amount of platinum it contains, thereby bringing the cost down to a level that the auto industry might find more palatable.

The biggest question now is how durable the alloy will prove to be in comparison to the unadulterated metal. According to Strasser, "The initial results show that durability is improved over pure platinum, but only longer-term testing can tell."

## COMPUTERS AND NETWORKING

### 3D MODELS FROM INTERNET SNAPSHOTS



■ Left: Representative snapshot used in the creation of (right) virtual 3D image.

PHOTO BY WOLFGANG WEDENIG. VIRTUAL RECONSTRUCTION BY MICHAEL GOESELE, TU DARMSTADT.

If you are one of the 10 million members, you already know that Flickr ([www.flickr.com](http://www.flickr.com)) is a photo management and sharing site where users post their favorite snapshots and show them to the rest of the world. Reportedly, it now holds more than a billion images that

you can explore by keyword, location, and other parameters, and you can find plenty of anything. For example a search on the keyword "warthog" returned 11,327 results as of this writing.

Now a group at the University of Washington ([www.washington.edu](http://www.washington.edu)) is making novel use of this resource to create virtual 3D models of the world's famous landmarks, e.g., Notre Dame Cathedral and the Statue of Liberty.

The first step is to download as many as 60,000 photos with a common tag, in this case "Statue of Liberty." A computer scans through them, keeping images that are deemed useful and dumping those that have obstructions or are of low quality. A UW-developed tool called Photo Tourism then calculates where the photographer was standing, interprets the different views, and creates a 3D reconstruction of the landmark.

The process takes a while; a reconstruction of St. Peter's Basilica, using 151 photos taken by 50 different photographers, took something less than two hours. But the resulting renderings — although not quite architecturally perfect — are pretty impressive.

Perhaps even more impressive is the ultimate goal, as stated by Steve Seitz, a UW associate professor: "The long-term vision is to be able to reconstruct the detailed geometry of all the structures on the surface of the Earth."

To make sure all appropriate architectural treasures are included, I'll be uploading all my snapshots of the Wot-a-Dog restaurant in New Carlisle, OH, which so far has been ignored.

### STREAM PROCESSOR INTRODUCED

The news on the hardware side is the FireStream 9170 stream processor and its accompanying software developer kit from Advanced Micro Devices ([www.amd.com](http://www.amd.com)). The chip, which should be available about the time you read this, is designed to

apply the parallel processing power of graphics processing units (GPUs) to the high-performance computing (HPC) market.

The 9170 is billed as the world's first stream GPU with double-precision floating point capabilities, which gears it up for scientific and engineering calculations. It offers up to 500 GFLOPS of computing power, putting it in the low-end supercomputer category, and yet it consumes less than 150W.

The MSRP is set at \$1,999, which should put machines that employ it within the reach of anyone who needs one. Watch for the 9170, coming to a desktop near you.

### THINKING ABOUT WORKSTATIONS

On the system level, Lenovo ([www.lenovo.com](http://www.lenovo.com)) has introduced its first new Think brand in five years, consisting of the ThinkStation S10 (single processor) and D10 (dual). These are designed for improved performance and reliability in demanding data and graphics-intensive environments such as CAD/CAE, oil and gas exploration, design automation, and other fields.

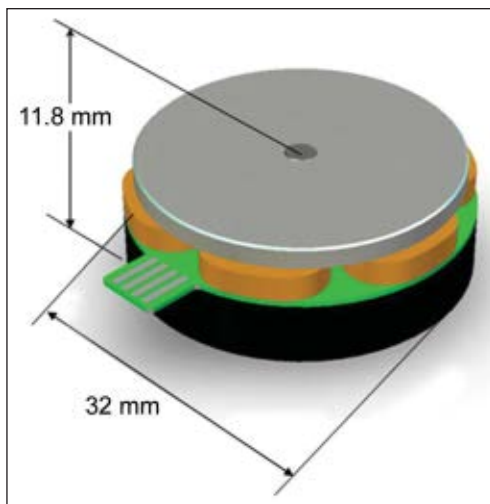
They are based on the Quad-Core Intel® Xeon® processor 5400 series and Intel® Core™2 Extreme processors, built on a new 45 nm technology that offers nearly double the transistor density to boost efficiency and performance.

Lenovo is offering a variety of storage, graphics adapters, memory, and rail kits for the workstations, which also come with a range of ThinkVantage technologies including Rescue and Recovery, Client Security System, and Image Ultra Builder. The machines are base priced at \$1,199 and \$1,799.

## CIRCUITS AND DEVICES

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■ Diagram of a nuvoDisc flat, brushless motor.

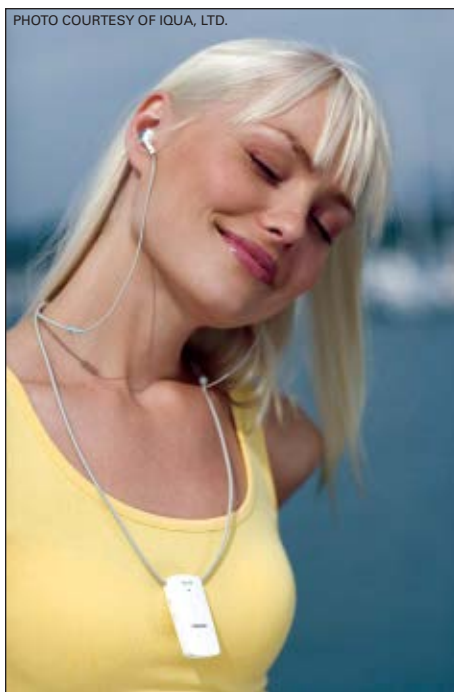
feature, Portescap ([www.portescap.com](http://www.portescap.com)) has introduced the nuvoDisc™ family of flat, brushless DC motors. The footprint is only 32 mm dia. by 11.7 mm length (or 11.8, if the diagram is correct), making them particularly well suited for tight spaces

such as in portable respirators and barcode scanners. The high-speed, slotless version is said to reduce vibration and eliminate cogging for smoother operation and better accuracy.

A slotted design is also available for applications requiring detent torque. With speeds of up to 50,000 rpm and mechanical power output of up to 30W (10 Nm of maximum continuous output torque), nuvoDisc claims to deliver the highest efficiency among all miniature DC motors. Prototypes are now available from regional sales offices or the company website.

## WIRELESS STEREO HEADSET FOR MUSIC, PHONE

**A** new offering for people who are concerned about “keeping your sense of style and class — everywhere



■ The Iqua BHS-702 pendant.

you go” is the Iqua BHS-702 Bluetooth® Pendant wireless stereo headset from Finland’s Iqua Ltd. ([www.iqua.com](http://www.iqua.com)). Established in 2004 largely by former Nokia employees, its stated mission is to “create state-of-the-art design products that improve the quality of life, enjoyment, and user satisfaction.”

The BHS-702 features A2DP (Advanced Audio Distribution Profile) technology for wireless stereo listening, and it fades the music when a cell call comes in and gives the wearer the option of answering the call or ignoring it via a single pushbutton.

A two-hour charge will give you nine hours of talk, seven hours of music, and 150 hours standby time. Early reviews were generally positive, although it has been noted that the pendant configuration puts the microphone too far from your mouth and increases noise as the device scrapes across your clothing. But it is trendy and colorful, so not everyone will care. You can pick one up from the Iqua website for 79 Euros (about \$116 at present). **NV**

## INDUSTRY AND THE PROFESSION

### FUTURE OF SCIENCE OUTLOOK UPDATED

**W**hen it was published four years ago, the US Department of Energy’s *Facilities for the Future of Science: A 20-Year Outlook* was the first such forward-looking document ever produced by a government science funding agency. It’s not light reading, but it does at least demonstrate that there is a method behind the government’s madness, and it furnished an overview of 28 new and upgraded scientific facilities that were to be supported in a variety of fields for two decades, including fusion energy, advanced scientific computation, materials science, biological and environmental science, and high energy and nuclear physics.

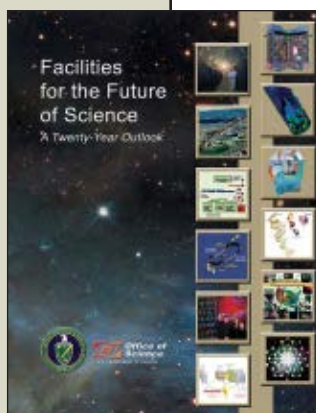
The DoE has now published an interim report that provides an update of the status of the original 28 facilities. According to Under Secretary for Science Dr. Raymond L. Orbach, “Our

purpose [in the interim report] is to give our citizens, legislators, and stakeholder communities a relatively digestible summary of where our Facilities Outlook stands today and a flavor for the continual careful effort of analysis, evaluation, and internal and external review that goes into our facilities planning and decision-making.”

The best part is that you can get a copy of both the original and interim documents for free. As one might expect when dealing with the government, direct links to the documents are either well hidden or nonexistent on the DoD website, and the actual URL is virtually impossible to type. But never fear. You now can just log onto [jkeckert.com/future.html](http://jkeckert.com/future.html) and drop them onto your hard drive. (The “Layla” video mentioned in the nanoradio section is there, as well.)

■ The DoE’s “Facilities for the Future of Science,” now updated.

PHOTO COURTESY OF US DEPARTMENT OF ENERGY.







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■ BY JON WILLIAMS

## THE POWER OF NETWORKING

**FOR AN ACTOR ATTEMPTING TO MAKE HIS WAY** in Hollywood, the word “networking” takes on a whole host of meanings. It’s a crazy business, really, and what most of us find is that those with the same goals, e.g., becoming an established actor, are not abundantly helpful to each other (a few are downright malicious). So, “networking” — actor to actor, that is — is mostly bupkis in my book. Now, I do have a “Hollywood” network, but the only actors in it are very well established, if not particularly well known. Most of my friends in the business do other things: make-up, special FX, etc., and the person that I network with most is a guy named Peter who, like me, is one of those techno-artistic types. Peter directs TV commercials, has worked for a major studio directing a TV series and doing special effects, and oh, by the way, just happens to be a fantastic electronics engineer who uses the SX in many of his projects. He even maintains the SX-Key IDE for Parallax — how could we not get along?!

**A**bout three or four times a month, Peter and I meet at one of our favorite restaurants in downtown Burbank, CA, just a stone’s throw from the Warner Brothers and Disney lots. The food is great, the service is great, and they never seem to mind that we will stay at the table long past the pasta, mostly talking about electronics. We usually have a little show-and-tell for each other, sharing current projects and exchanging ideas. The meetings are always educational and, for me, it’s the best way to “do lunch” in Hollywood.

Peter has been incredibly generous with his knowledge, particularly on a subject that I’ve been slow to approach: microcontroller networking. Sure, I’ve done very simple stuff, but having spent that last two Halloweens at Peter’s home watching (with hundreds of others) his incredible animatronics display, I am pushing myself to jump in and give “real” microcontroller networking a go. Lucky for me, I have the benefit of Peter’s experience on this topic, as he’s spent the last several years developing and improving his networked animatronics control system.

Several years back, Peter set out to design a very flexible, fully modular animatronics control system that he could manage from a simple PC. Well, having seen it in action, I can tell you that he succeeded, and you can see for yourself by visiting his website at [www.socalhalloween.com](http://www.socalhalloween.com). His system runs on an RS-485 network with several types of network nodes; the most sophisticated being the

animation controller that is able to receive an animation frame while playing another (the servo control output of the animation controller uses an SX28).

My goals are somewhat less sophisticated than Peter’s, though I’ve had them for quite some time. While I was living in Texas, I read about a man who built an enormous custom home; its size was somewhere on the order of 20,000 square feet. When he consulted the utilities companies, they estimated that his monthly heating and air conditioning expenses would be around \$4,000. He figured for that much money he could create a custom home management system and when he did, his energy bills were reduced to under \$400 per month. Along the way, he discovered that a lot of “energy efficient” appliances were not performing to their stated specifications and he forced some manufacturers to restate their specs or fix the products.

Today, the concept of “going green” is very popular, and it should be — a penny saved is a penny earned, especially when it’s precious energy. So my system is going to be very straightforward with the ultimate goal to monitor and control my home from a simple PC; making it “smart” and, if I do it well, energy efficient.

As this is the beginning of what I expect to be a long journey, I’m borrowing another one of Peter’s good ideas: I’m creating a prototyping system for an SX-based network node. What this means is that my generic network node



PCB will have a processor and the RS-485 interface, and a small breadboarding area to add custom circuitry as needed for a given node. Let's have a look at the hardware.

Figure 1 shows the SX28 processor and RS-485 interface (MAX489 or equivalent). As you can see, it is, in fact, very generic. The design uses port RA for communications and ports RB and RC for I/O that is specific to the node. For the purposes of the rest of this article, my node is going to be a 10-segment LED display. I'm starting with simple hardware so that I can get my head around the requirements of managing network messages.

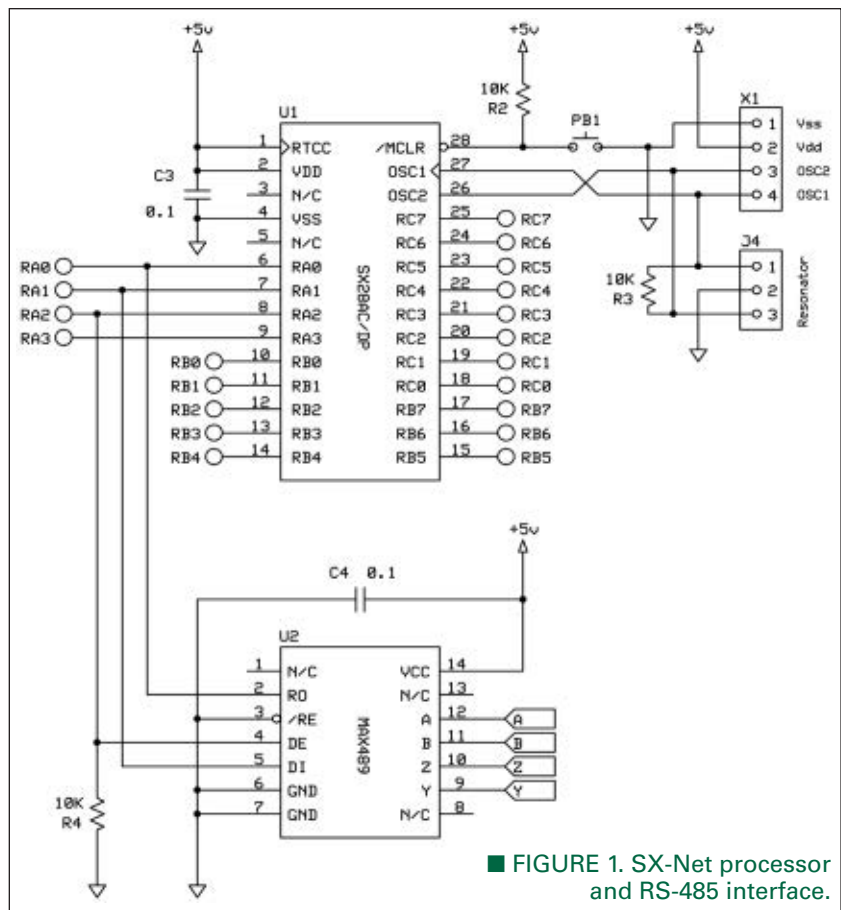
The node has dedicated RX and TX pins for the RS-485 link, so we can tie the MAX489 Receive Enable (/RE) pin to ground; that way, the SX will always be "listening." On the other side, however, we will want to selectively activate the Data Enable (DE) pin so that RS-485 output from the node is active only when transmitting.

Figure 2 shows the power supply and RS-485 connections. Using RJ-45 jacks allows us to transmit full-duplex data on inexpensive CAT-5 cables. We can even put power on the cable to handle low-current nodes. When taking power from the CAT-5 cable, jumpers JP1 and JP2 should be installed. Otherwise, they should be removed. If using local power, you must remove JP1 — *please be careful with this*.

Jumpers JP3 and JP4 enable the line terminators. If a node is the last on the "receive" end, then JP3 should be installed, otherwise removed. If the node is the first on the "transmitting" end, that is, this node is the "master," then JP4 should be installed. I'm using a PC as my master node but there's no reason we can't have a network of SX-only nodes, with one being assigned as the master controller.

Okay, the hardware is very simple, and that's by design as this is a prototyping system. One problem I did run into is the hole-count limitation when using ExpressPCB's mini board service. After getting my components laid out, I just filled as much [logical] space as possible with standard pads. As I went to order boards, I got a dialog that informed me I had too many holes for a mini board — so keep this in mind when you're prototyping with ExpressPCB.

Since most of my projects involve the SX, I've become very comfortable with "virtual peripherals" and have created several code modules that I plug in as needed. A couple modules that get a lot of use in what I do are the buffered receive and transmit UARTs; these modules allow us to receive and transmit serial data in "the background" while our foreground code is doing other things. The receive UART for this project is a buffered version of what we used in the lighting controller we did last November. This project uses the complimentary transmit UART that has a little addition to manage the MAX489 DE pin. Let's look at the modifications for controlling the MAX489.



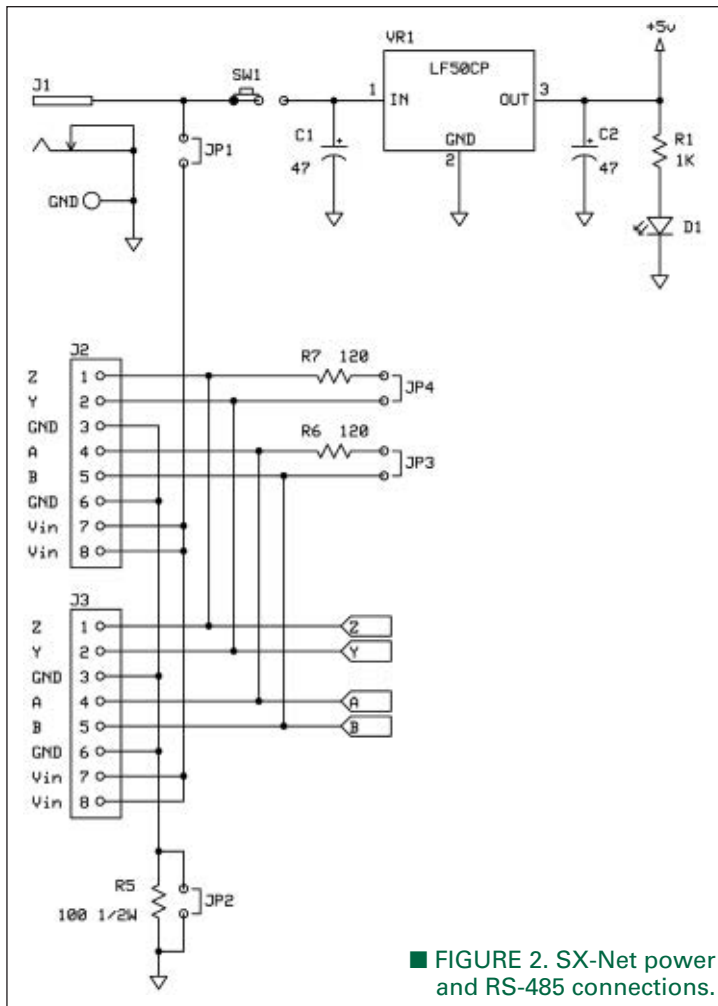
■ FIGURE 1. SX-Net processor and RS-485 interface.

```
Transmit:
ASM
    BANK    txSerial
    CLRB    txDivide.BaudBit
    INC     txDivide
    JNB     txDivide.BaudBit, TX_Exit
    TEST    txCount
    JZ      TX_Buffer
    STC
    RR      txHi
    RR      txLo
    MOVB    TX, txLo.6
    DEC     txCount
    JMP     TX_Done
```

```
TX_Buffer:
    TEST    txBufCnt
    JZ      TX_Exit
    SETB    TxEnable
    MOV     W, #txBuf
    ADD     W, txTail
    MOV     FSR, W
    MOV     txHi, IND
    CLR     txLo
    MOV     txCount, #11
    INC     txTail
    CLRB    txTail.3
    DEC     txBufCnt
    JMP     TX_Done
```

```
TX_Exit:
    JNB     TxEnable, TX_Done
    CJA     txBufCnt, #0, TX_Done
    CJA     txCount, #0, TX_Done
    CLRB    TxEnable
```

```
TX_Done:
    BANK    0    ENDSM
```



■ FIGURE 2. SX-Net power and RS-485 connections.

One of the great aspects of SX/B is the ability to easily fold assembly code segments into a BASIC program — that's what I did here; the UART code is really a modification of that found in Günther Daubachs' excellent book, *Programming the SX Microcontroller*. I modified the buffering to work within the same RAM bank as the other transmit variables and, for this project, included control of the MAX489.

In the section at **TX\_Buffer**, the DE pin (called TxEnable in the program) is taken high with **SETB** when a byte is about to be moved from the transmit ring buffer into the transmitter output (*txHi*). Since this byte won't start going out until the next interrupt, there is plenty of time for the DE pin to stabilize. The DE pin will stay high until the transmit buffer is empty (*txBufCnt* is 0) and there are no more bits to be transmitted (*txCount* is 0).

Okay, now that we can receive and transmit bytes in the background, it's time to talk protocol. The neat part about this is we get to make it up, which, in fact, turns out to be the tough part too; sometimes it's just easier to work from an established specification. In my case, I borrowed quite a lot from Peter's protocol, making a few changes that simplify the system and tie into my long-term goals.

The protocol is, essentially, peer-to-peer, so any node can talk to any other node. This opens the door to all kinds

of interesting possibilities. The "sender" node will transmit a four-byte header that is followed by a data packet if required for the specific message. The entire transmission is configured as follows:

<b>Receiver</b>	Receiver node (1 to 127) + \$80 – to designate start of header
<b>Sender</b>	Node sending the packet (1 to 127)
<b>Message</b>	Request or Command Message
<b>Packet Size</b>	Number of bytes in data packet (0 to n)
<b>Data Bytes</b>	Data used by Message (optional)

The minimum transmission size will be four bytes (the header): the receiver, the sender, the message, and a zero when there are no data bytes. The receiver address will have BIT7 set to designate the start of a new header — the MIDI protocol uses this strategy and we're going to borrow from it.

The node we're going to create will be a simple I/O slave that will respond to (valid) commands and requests from another node. We'll use a VB program to send the messages from a PC. Since the node is a slave, it waits for bytes to show up in the receive buffer and then processes them accordingly. The first part handles the basic message header.

```

Main:
  rxNode = RX_BYTE
  IF rxNode.7 = 0 THEN Main

Validate_Start:
  rxNode.7 = 0
  IF rxNode = GLOBAL_NODE THEN Get_Sender_Node
  IF rxNode <> MY_NODE THEN Main

Get_Sender_Node:
  txNode = RX_BYTE
  IF txNode.7 = 1 THEN
    rxNode = txNode
    GOTO Validate_Start
  ENDIF

Validate_Global_Sender:
  IF rxNode = GLOBAL_NODE THEN
    IF txNode <> MASTER_NODE THEN Main
  ENDIF

Get_Message:
  msgNum = RX_BYTE
  IF msgNum.7 = 1 THEN
    rxNode = msgNum
    GOTO Validate_Start
  ENDIF

Get_Packet_Length:
  packLen = RX_BYTE
  IF packLen.7 = 1 THEN
    rxNode = packLen
    GOTO Validate_Start
  ENDIF
  
```

When a byte comes in, we need to check to see if BIT7 is set as this indicates the start of the header. When we get such a byte, BIT7 is cleared and we pull the next byte from



the input buffer — this is the sender node. If the receive node was designated as global (address 0), the program ensures that the sender was the master; in my system only the master node is allowed to send global commands. Finally, the message number and packet length bytes are pulled from the stream.

Since it is possible for a transmission to be interrupted and then restarted, we must test every byte that comes in for BIT7 being set. By doing this check, we can always re-sync the node with the start of a new header.

If the command or request includes data, the packet length byte will be one or greater. I don't expect to have long packets in my home control system so the buffers are fairly small. Here's how we receive any data bytes.

```
RX_Raw_Packet:
  idx = 0
  DO WHILE idx < packLen
    tmpB1 = RX_BYTE
    IF tmpB1.7 = 1 THEN
      rxNode = tmpB1
      GOTO Validate_Start
    ELSE
      fifo(idx) = tmpB1
      INC idx
    ENDIF
  LOOP
```

As above, each new byte is checked to ensure it's not a header start byte; if not, it gets moved into a temporary array called *fifo*().

I know what you're thinking: "If we can't use BIT7, how do we transmit values greater than 127?" We're going to borrow another strategy from MIDI and use two bytes: The first byte will contain the lower seven bits of the eight-byte value and the second byte will hold BIT7. Remember, we don't always need all eight bits for a given command, so we only use this scheme when an eight-bit value is required.

After receiving the packet and any data bytes, we will use a simple routing section to process the incoming transmission. By doing this, we end up simplifying the message handlers.

```
Route_Message:
  IF msgNum = QRY_REQ THEN Unit_Acknowledge
  IF msgNum = DEV_RST THEN Device_Reset
  IF msgNum = SET_BIT THEN Set_One_Bit
  IF msgNum = GET_BIT THEN Get_One_Bit
  IF msgNum = WR_PORT THEN Write_Port
  IF msgNum = RD_PORT THEN Read_Port

  ' if we get here, message is not used by this node

Bad_Message:
  msgNum = MSG_NAK
  packLen = 0
  GOTO Unit_Reply
```

No mystery here: If the message is known to be used by this node, then the program is routed to the appropriate handler, otherwise the response MSG\_NAK is returned to the sender. Since we're now dealing with messages, let's have a

look at what's defined and explain the logic behind them.

QRY_REQ	CON	\$01
QRY_ACK	CON	\$02
MSG_ACK	CON	\$03
MSG_NAK	CON	\$04
MSG_FAIL	CON	\$05
DEV_RST	CON	\$0F
SET_BIT	CON	\$10
GET_BIT	CON	\$11
GET_BIT_ACK	CON	\$12
WR_PORT	CON	\$20
RD_PORT	CON	\$21
RD_PORT_ACK	CON	\$22
WR_CHAN	CON	\$30
RD_CHAN	CON	\$31
RD_CHAN_ACK	CON	\$32

The first message, QRY\_REQ, is used by the sender to "ping" the receiver; if the receiver is present then it responds with QRY\_ACK. The next four messages are used to respond to commands or requests for data from the receiver. If node is able to complete a request and there is no data to be returned, then it will respond with MSG\_ACK. If the message sent isn't used by the node, then the response is MSG\_NAK. If a valid message is sent with bad data (e.g., a bad port number), then the response will be MSG\_FAIL. The final message in this lower group, DEV\_RST, will usually be issued by the master to tell a node to reset itself.

For a simple I/O node, I've defined three sets of commands: one for bit-level control, one for port-level control, and a third for setting values (called channels) within the program space. The set and write commands will respond with MSG\_ACK, MSG\_NAK, or MSG\_FAIL as appropriate. The get and read commands have dedicated responses for the return data; the logic being this aids the "sender" side of the exchange when a lot of packets are flying around.

Let's have a look at a few of the handlers.

```
Unit_Acknowledge:
  msgNum = QRY_ACK
  packLen = 0
  GOTO Unit_Reply
```

The **Unit\_Acknowledge** handler is the simplest: it sets the message to QRY\_ACK, the return packet length to zero, and then sends the reply. The reason for this process is to allow a master to poll all the expected slave devices to ensure that they're actually online; there is no reason for sending command messages to a node that is not connected.

Now for something a little more interesting. We'll accept a level for one of the I/O pins on the node. I happened to find a 10-segment bar-graph LED in my junk drawer so I soldered that onto the PCB. With just 10 LEDs on the node, the handler will only accept bit numbers between 0 (on RB.0) and 9 (on RC.1) — if you use more outputs, be sure to adjust the code accordingly.

```

Set_One_Bit:
    tmpB1 = fifo(0)
    tmpB2 = fifo(1)

    IF tmpB1 < 10 THEN
        IF tmpB1 < 8 THEN
            tmpB1 = 1 << tmpB1
            IF tmpB2.0 = 1 THEN
                RB = RB | tmpB1
            ELSE
                tmpB1 = ~tmpB1
                RB = RB & tmpB1
            ENDIF
        ELSE
            tmpB1 = tmpB1 - 8
            tmpB1 = 1 << tmpB1
            IF tmpB2.0 = 1 THEN
                RC = RC | tmpB1
            ELSE
                tmpB1 = ~tmpB1
                RC = RC & tmpB1
            ENDIF
        ENDIF
    ELSE
        msgNum = MSG_ACK
        packLen = 0
    ELSE
        msgNum = MSG_FAIL
        packLen = 0
    ENDIF
    GOTO Unit_Reply

```

The **Set\_One\_Bit** handler pulls the bit number and bit level from the *fifo()* array. This message doesn't use "stuffed" data bytes as the 127 limit exceeds the pin count on the SX48. Now, if you want to add shift-registers so that there are more than 128 discrete outputs on the node, then you'll need to modify this handler to accommodate the expansion.

The first test is of the bit number. Assuming it's valid for the node, the program determines which I/O port (RB or RC) holds that bit. A mask is created and if BIT0 of the specified level is one, the mask is ORed with the control port which makes the I/O pin go high. If BIT0 of the specified level is zero, the mask is inverted and then ANDed with the control port which makes the I/O pin go low. The node will return MSG\_ACK after the bit is manipulated — unless the bit number was bad — then it will return MSG\_FAIL.

The WR\_PORT and RD\_PORT message deal with eight-byte values, so let's see how we receive and return them using the seven-bit container bytes in the packet.

```

Write_Port:
    tmpB1 = fifo(0)

    IF tmpB1 < 2 THEN
        tmpB2 = PACKW_TO_VAL fifo(1), fifo(2)
        IF tmpB1 = 0 THEN
            RB = tmpB2
        ELSE
            RC = tmpB2 & %00000011
        ENDIF
        msgNum = MSG_ACK
        packLen = 0
    ELSE
        msgNum = MSG_FAIL
        packLen = 0
    ENDIF
    GOTO Unit_Reply

```

The WR\_PORT message requires three data bytes: the port number and two (seven-bit) bytes that make up the eight-bit value for the specified port. The first check, of course, is the port number. On my little I/O node RB is defined as port 0 and RC as port 1. If the specified port number is greater than one, then we will abort with a MSG\_FAIL response.

When the port number is valid, then we'll use *fifo(1)* and *fifo(2)* to reconstruct the eight-bit value with **PACKW\_TO\_VAL**. This function expects two seven-bit values passed LSB, then MSB, and will return a properly reconstructed word. In our program, we'll only be using the low byte of the returned word, but you can reuse this code in a MIDI application as it will properly handle 14-bit values.

```

FUNC PACKW_TO_VAL
    tmpW1 = __WPARAM12
    tmpW1_LSB = tmpW1_LSB << 1
    tmpW1 = tmpW1 >> 1
    RETURN tmpW1
ENDFUNC

```

Reconstructing a clean, 14-bit value from two seven-bit values is pretty easy. We move the bytes into *tmpW1* and then shift the lower byte left by one to close the gap at BIT7. Now we can shift the entire word right by one to re-align everything to BIT0. That's it; the 14-bit value is reconstructed and can be returned to the caller.

The **Write\_Port** handler will route the reconstructed byte to the appropriate port based on the contents of *fifo(0)*. Since I'm only using two bits on RC, the value is masked before it's written to that port.

The **Read\_Port** handler allows us to read the state of a port on the SX. The sender will pass the port number and expects to get three data bytes back: the port number and two seven-bit bytes that will be reconstructed into a single eight-bit port value.

```

Read_Port:
    tmpB1 = fifo(0)

    IF tmpB1 < 2 THEN
        IF tmpB1 = 0 THEN
            tmpB2 = RB
        ELSE
            tmpB2 = RC & %00000011
        ENDIF
        tmpW1 = VAL_TO_PACKW tmpB2
        msgNum = RD_PORT_ACK
        packLen = 3
        fifo(1) = tmpW1_LSB
        fifo(2) = tmpW1_MSB
    ELSE
        msgNum = MSG_FAIL
        packLen = 3
        fifo(1) = 0
        fifo(2) = 0
    ENDIF
    GOTO Unit_Reply

```

This routine uses the **VAL\_TO\_PACKW** function to split the byte value into two seven-bit containers. To keep things



simple, we'll use a word variable to receive the return value from **VAL\_TO\_PACKW**.

```

FUNC VAL_TO_PACKW
  IF __PARAMCNT = 1 THEN
    tmpW1 = __PARAM1
  ELSE
    tmpW1 = __WPARAM12
  ENDIF

  tmpW1 = tmpW1 << 1
  tmpW1_LSB = tmpW1_LSB >> 1
  tmpW1_MSB = tmpW1_MSB & $7F
  RETURN tmpW1
ENDFUNC

```

This function is set up to accommodate bytes or words so that we can also use it in future MIDI applications. The value to split is moved into *tmpW1* and then shifted left. This moves BIT7 of the lower byte into BIT0 of the upper. The next step is to shift the lower byte right by one to realign its BIT0; BIT7 of the low byte will now be 0 as required by the protocol. The final step is to ensure that BIT7 of the high byte is clear before returning the new value.

We will move the low byte of the return value to *fifo(1)* and the high byte to *fifo(2)* – *fifo(0)* already holds the port number so we don't have to change that. The message is set to *RD\_PORT\_ACK*, the packet length to three, and then we send the response.

While chatting with Peter about networking, he told me – and he was – that designing these kinds of projects can turn into a bit of a chicken-and-egg dilemma. Testing a node requires another node, and writing the code for that requires specifications on both ends. Case in point is when I was sending a bad port number from my PC node; the slave node originally sent a *MSG\_FAIL* packet (just four bytes), but my PC node was expecting success and waiting for seven. To keep things easy – and easy is usually best – the slave node will always have a three-byte packet for *RD\_PORT*, even if the return message is *MSG\_FAIL*. The port number is maintained so the master node can deal with it, and the incoming transmission processing is simplified by assigning an expected return message length to each command.

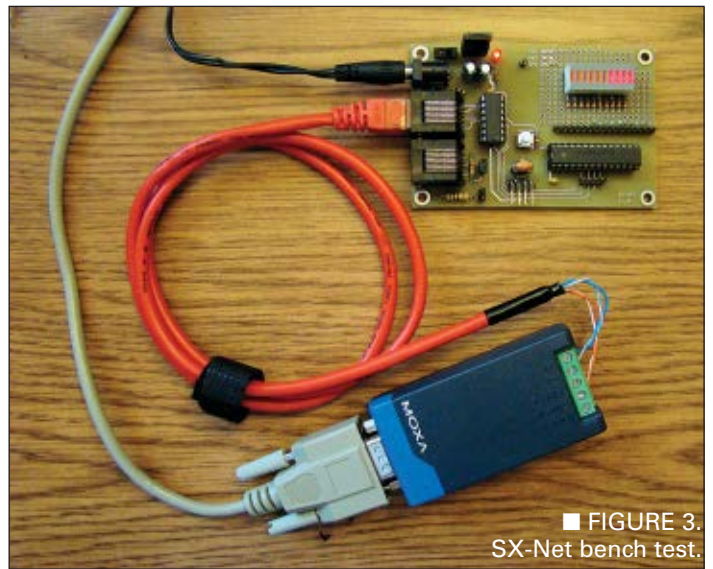
You've probably noticed that all message handlers jump to a routine called **Unit\_Reply**. Here it is:

```

Unit_Reply:
  IF rxNode = MY_NODE THEN
    rxNode = txNode | $80
    TX_BYTE rxNode
    TX_BYTE MY_NODE
    TX_BYTE msgNum
    TX_BYTE packLen
    idx = 0
    DO WHILE idx < packLen
      TX_BYTE fifo(idx)
      INC idx
    LOOP
  ENDIF
  GOTO Main

```

The only time a node will send a response is when the

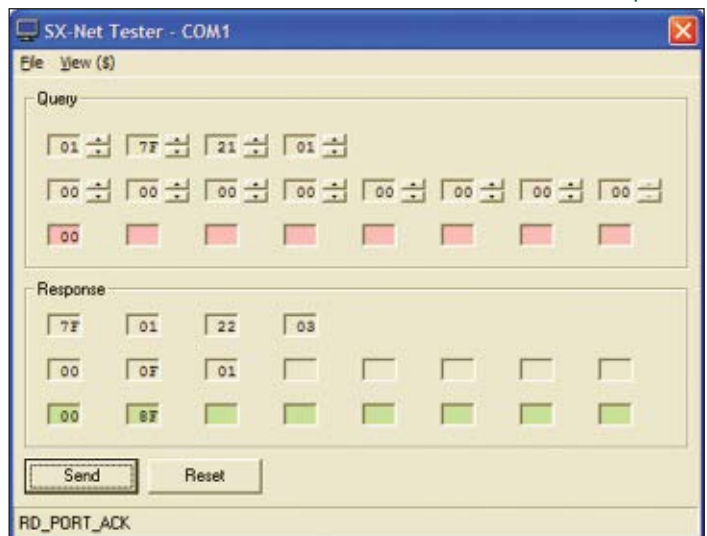


■ FIGURE 3. SX-Net bench test.

node is individually addressed. A node could, for example, send a message to the global address of 0 that all nodes react to; in this case, there will be no responses from the nodes as they would likely end up stomping on each other and the messages would be trashed. You can see that **Unit\_Reply** takes the sender node address and turns it into the header start byte by setting BIT7.

Okay, now we have the makings of a reasonably sophisticated control network using the SX, and can do all kinds of cool things with it. Figure 3 shows my first prototype node along with a port-powered RS-485 interface, and Figure 4 shows the VB test node for experimenting with messages (the compiled program and source code is included in the download files for the article). In the Query frame, you can see four primary values; these comprise the message header. The middle row of inputs allows for uncompressed data. The lower row of [red] boxes shows the actual packet bytes transmitted to the receiver node. The Response frame is similarly constructed, except that the middle line holds seven-bit "packed" values and the lower

■ FIGURE 4. SX-Net test panel.



## ► PARTS LIST

Item	Description	Part No.
► C1, C2	47 $\mu$ F	647-UVR1V470MDD
► C3, C4	0.1 $\mu$ F	80-C315C104M5U
► D1	LED	859-LTL4222N
► J1	2.1 mm barrel	806-KLDX-0202-A
► J2-J3	RJ-45 R/A	571-5202514
► J4	Machine pin	506-510-AG91D
► JP1-JP4	Pin strip header	517-6111TG
► Jumpers	0.1" shunt	538-15-29-1024
► PB1	N.O. button	612-TL59F160Q
► PCB		<b>ExpressPCB.com</b>
► R1	1K	299-1K-RC
► R2-R4	10K	299-10K-RC
► R5	100 1/2W	293-100-RC
► R6-R7	120 $\Omega$	291-120-RC
► RES1	20 MHz	Parallax 250-02060
► S1	28-pin DIP	571-1-390261-9
► S2	14-pin DIP	571-1-390261-3
► SW1	Slide switch	506-SSA12
► U1	SX28AC/DP	Parallax SX28AC/DP
► U2	MAX489	837-ISL8489IP
► VR1	LF50CP	511-LF50CP
► X1	R/A header	517-5111TG

*Note: All part numbers are from Mouser unless otherwise noted.*

[green] boxes hold the reconstructed bytes.

## THE BIG SQUEEZE

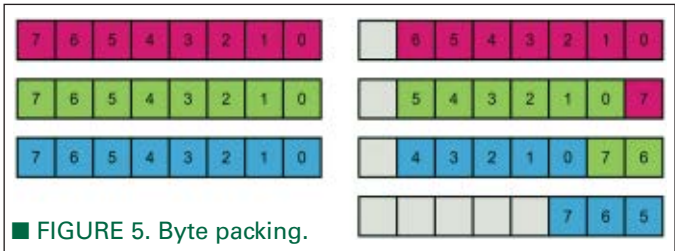
At some point, you will probably want to create a node that requires more than one eight-bit value for a message and you don't want to use two bytes for each. Peter came up with a neat compression solution for his network and I've created it so I can use it. Have a look at Figure 5 to see how Peter compresses several eight-bit values into seven-bit containers.

Since we will typically manipulate blocks of values, I created a subroutine called **UNSQUEEZE** that will take two bytes from an input buffer and move them into a single byte of an output buffer. To use this routine, we will pass a pointer to the start of the input buffer, an offset for the desired value, and a pointer to the start of the output buffer.

```
SUB UNSQUEEZE
  src = __PARAM1
  offset = __PARAM2
  dest = __PARAM3

  src = src + offset
  dest = dest + offset
  dByte = __RAM(src)
  dByte = dByte >> offset
  INC src
  dbMSB = __RAM(src)
  offset = 7 - offset
  dbMSB = dbMSB << offset
  dByte = dByte | dbMSB
  __RAM(dest) = dByte
ENDSUB
```

The actual source and destination addresses are incremented by the offset to get to the LSB of the target byte. By



■ FIGURE 5. Byte packing.

doing this math in the subroutine, we simplify the interface to it — we don't have to remember the @ (address of) operator with the array name; we just use the name on its own. The low bits of the output byte are retrieved using the `__RAM()` array and shifted right by the offset to re-align BIT0. The source address is then incremented to get to the upper bits. This value is shifted left to move the bits to the correct position and then the two bytes are ORed together to reconstruct the eight-bit value. Finally, the `__RAM()` array is used to move the reconstituted value to the desired output address.

The compliment of **UNSQUEEZE** is — no big surprise — **SQUEEZE**; we can use this to create a compressed packet to send to another node.

```
SUB SQUEEZE
  src = __PARAM1
  offset = __PARAM2
  dest = __PARAM3

  src = src + offset
  dest = dest + offset
  dByte = __RAM(src)
  dbCopy = dByte
  destVal = __RAM(dest)
  dByte = dByte << offset
  dByte = dByte & $7F
  destVal = destVal | dByte
  __RAM(dest) = destVal
  INC dest
  offset = 7 - offset
  destVal = dbCopy >> offset
  __RAM(dest) = destVal
ENDSUB
```

With **SQUEEZE**, the eight-bit value will be split based on its position in the output array, with the lower half ORed into the output array so that any previous values there are not disturbed. Let me suggest that the **FILL** subroutine be used to clear the output array before looping through the input array — in order — to create the compressed packet. It's a little bit of code, but now we can send seven full bytes using eight instead of 14, and this can be important if we have a lot of network traffic.

Okay, I think we should probably wrap it up right here. Order your boards, build a simple node, and start experimenting. I'd love to hear your ideas on home control, especially those ideas that allow us to conserve energy.

Until next time, Happy Networking with the SX! **NV**

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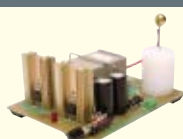


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5. General aircraft monitoring enthusiasts

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AM550K	AM Integrated Circuit Radio Learning Kit	\$22.95

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# Q&A

## WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:



**Mailbox Timer**



**Dimming Thermostat**



**Batteries in the Woods**

### ■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:

[Q&A@nutsvolts.com](mailto:Q&A@nutsvolts.com)

## FREQUENCY DIVIDER

**Q** I need a circuit to produce 3250 Hz and 65 Hz at the same time. I don't know if a CD4040, CD4060, or a PIC will do it; 50% duty cycle would be nice.

— Craig Sellen

**A** If you want crystal control, the frequency of the oscillator should be above 1 MHz for least cost. You need two dividers to get two arbitrary frequencies, so I will use the CD4040 twice. The oscillator frequency has to be divisible by both numbers, so multiplying  $65 \times 3250 \times 6 = 1.267500$  MHz. Multiplying by 5 also is above 1 MHz but requires more gates to decode. You could order a custom crystal but I will design using an R-C oscillator. A divide by 2 is needed to get 50% duty cycle, so I will use a CD4013 dual D flip-flop.

In Figure 1, the first divider output is 6,500 Hz. The decoder taps on the divider are found by determining the division ratio (195) and subtracting the largest power of 2 that will fit until the remainder is 1 ( $195 - 128 = 64 - 2$ ). The taps are at the first, sixth, and seventh flip-flop in the divider. A divide by 2 provides the 3,250 Hz signal which is then divided down to 130 Hz in the

CD4040 IC. The division ratio is 25, so  $25 - 16 = 8 = 1$  and the taps are at the third and fourth flip-flops of the CD4040. A divide by 2 gives the 65 Hz output. A CD4024 seven stage counter could have been used instead of the CD4040.

## TRANSFORMER CURRENT

**Q** Several months prior to his untimely demise, TJ Byers stated in the Q & A column, in answer to a reader's question about power supplies, that current in a transformer is not a sine wave. Mr. Byers did not elaborate on that subject as he was answering a somewhat different question, but it raised questions in my mind as to what is the current in a transformer if not a sine wave? I have been patiently waiting for some other reader to re-raise the question to see if you could tell us what current in a transformer truly is, if not a sine wave.

I am as perplexed now as I was then: If current in a transformer is not a sine wave, how does one go about calculating how much current is available when the AC is rectified? Since voltage is very definitely a sine wave and the DC value is markedly different from the AC value, it stands to reason the DC value of the current would follow the same rules.

To me, that makes sense as current and voltage are traded back and forth in a transformer and we calculate that trade-off via the 60 Hz sine wave. How is it that the current is not a sine wave? I don't quite get that. Could you please elucidate?

— Charles R. Rhines

**A** I believe Mr. Byers was speaking of a transformer driving a rectifier in a power supply. Without getting into nit-picking details of transformer nonlinearity and effects of nonlinear loads on the source voltage, the current in the power supply transformer pulses and is not sinusoidal.

Consider the case of a full wave circuit with an output capacitor and DC load as in Figure 2. The upper (blue) line is the output voltage; the lower line is the primary current (scale on the right). The capacitor is slowly discharged by the load; the rectifier replenishes the voltage only at the peak of the waveform. It was common in the old days to put an inductor in series between the rectifiers and the capacitor to make the pulses wider (see Figure 3).

Note that the output voltage is smoother, takes longer to reach a steady state, and the primary current pulses are wider. In fact, it is possible to make the inductor large enough that the current is sinusoidal, but I have never seen it done.



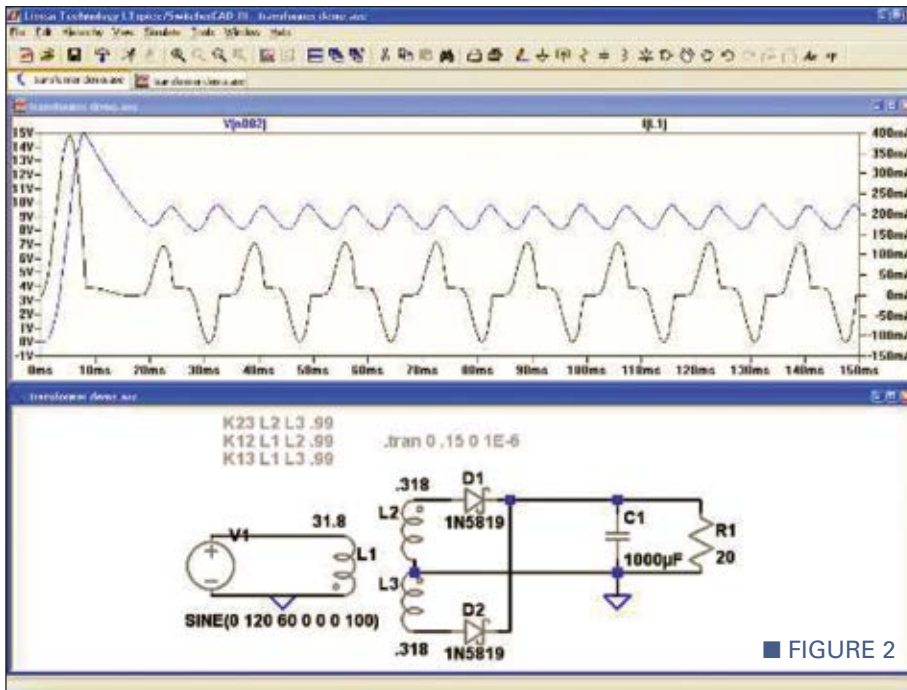


FIGURE 2

## 12 VOLT TO 9 VOLT REDUCER

**Q** I have a question that I've been trying to figure out for the past six months. Any advice you might have will be greatly appreciated.

I live in the woods and use 12V batteries for power. I have a bunch of music equipment like

pedals and samplers that run off of nine volts (mostly 500 mA) and I would like to make a converter 12V to 9V DC. Do you think it would be fine to just use a resistor? Do you have a simple schematic to recommend?

I found one that uses an ECG184, but I am not sure if it will put out the 1.5 amps that I would require to use three pedals at once.

— Annie

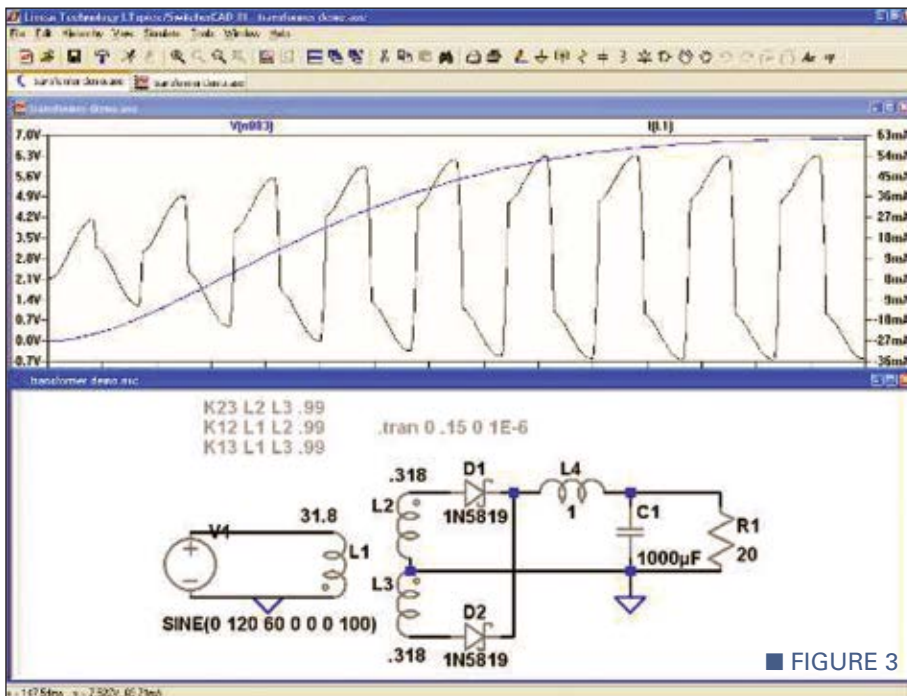
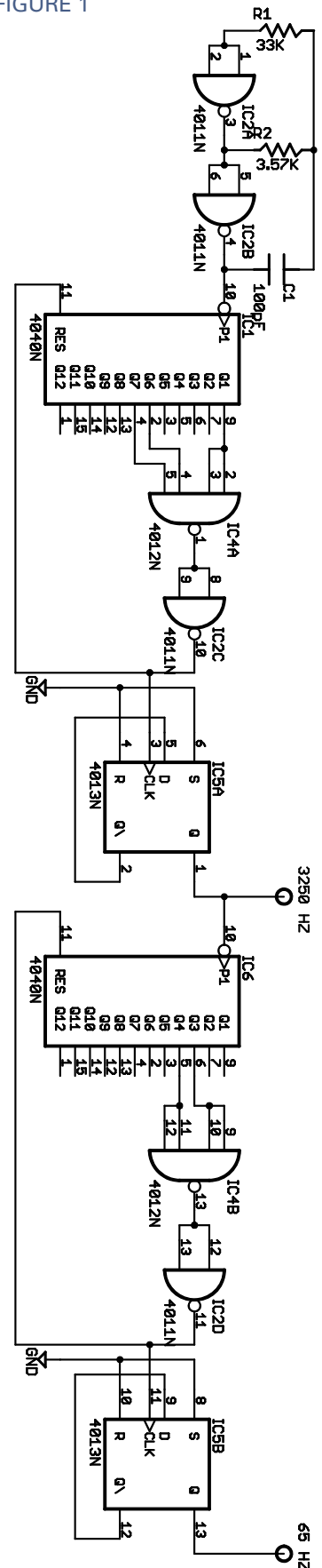
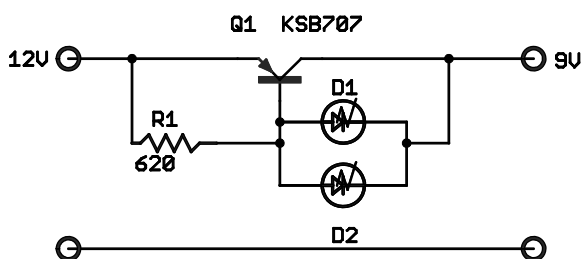


FIGURE 3

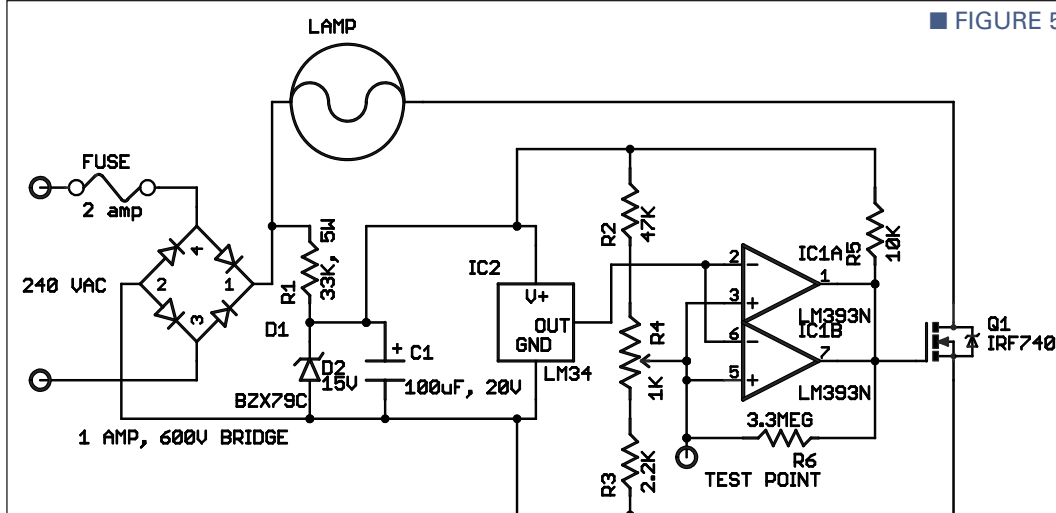
FIGURE 1





WWW.MOUSER.COM  
MOUSER PART NUMBERS

Q1	512-KSB707YTU_Q	\$1.06
R1	291-620-RC	\$0.40 FOR 10
D1, D2	78-TLHP5100	\$0.14 EA
HEAT SINK	567-657-20ABP	\$1.75



the second is just for safety. The resistor, R1, is just to provide a path for the leakage current of the two LEDs.

You can build it on perf board, soldering the leads together.

## DIMMING THERMOSTAT

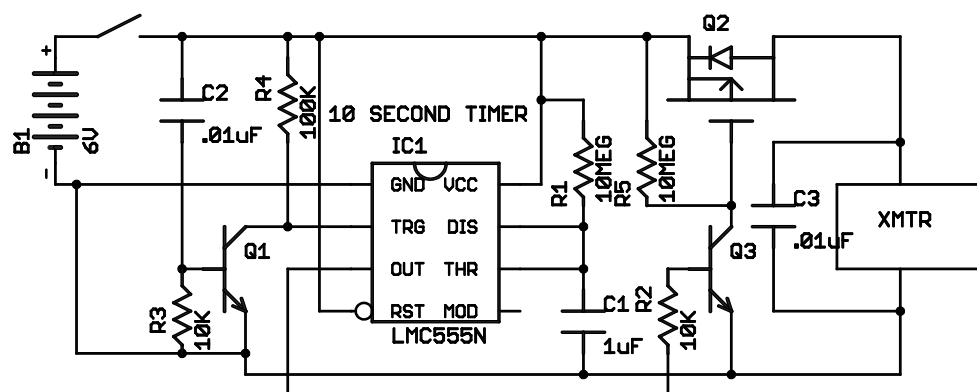
**Q** I want to build a dimming thermostat type circuit to control a 50 to 100 watt bulb at 240

VAC. It needs to have a settable range between 70 to 100 degrees F. When the set temperature is reached, the light should dim down to hold the desired temperature. I've looked at some simple diac/triac dimmer circuits. Is it possible just to add a thermistor in line with the potentiometer?

This is a very useful type of circuit for many animal/reptile keepers.

Many thanks for any advice you may have.

— Tony Flynn, Ireland



Q1, Q3 = 2N3904  
Q2 = 689-UP3203N3-G MOUSER PART NO.  
C1 = METALLIZED FILM

**A** In a triac dimmer, the temperature increases as the resistance is decreased; the thermistor resistance decreases as the temperature increases so it is not suitable to put in series with the potentiometer. I suggest using an LM34 temperature sensor which outputs 10 millivolts per degree F. An LED and cadmium sulfide cell could be used to control the triac, but I think rectifying to DC and using a



MOSFET is just as simple (see Figure 5).

Note that there is no capacitor filtering the voltage to the lamp because doing so would increase the average voltage and cause the lamp to burn out sooner. The zener diode and C1 provide 15 volts DC to the regulator circuit. The LM34 output is 10 millivolts per degree F, so 700 millivolts equals 70 degrees. You can use a voltmeter to measure the set temperature at the test point.

The feedback resistor, R6, provides about one degree hysteresis so the lamp does not start flickering. You might want to put the lamp in an opaque jar so the animal is not subjected to the light going on and off. Maplin only stocks the LM35 which is calibrated in degrees C, so you will need a conversion chart if you use that. The values of R2, R3, and R4 should be: 130K, 2K, and 2K.

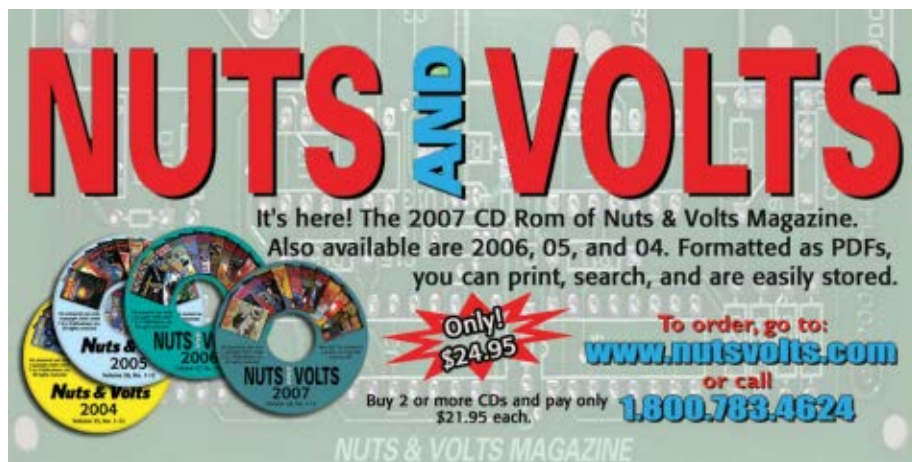
## MAILBOX TIMER

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— Anonymous

**A** The circuit shown in Figure 6 is necessarily connected to the battery as long as the mailbox door is open. The battery is rated 105 mAh and the circuit drain is about 1/4 mA so the battery life is about 16 days with the door open (not counting the transmitter current).

In Figure 6, when the door is opened, the switch closes. The charging of C2 turns on Q1 which pulls the trigger low and starts the 555 timer. The output goes high which turns on Q3, which then turns on Q2 and applies power to the transmitter. When C1 charges to 2/3rds of the battery voltage, the timer resets, turning Q2 off. It stays in that state until the door is closed and opened again. C3 is just an RF bypass for the transmitter power. **NV**



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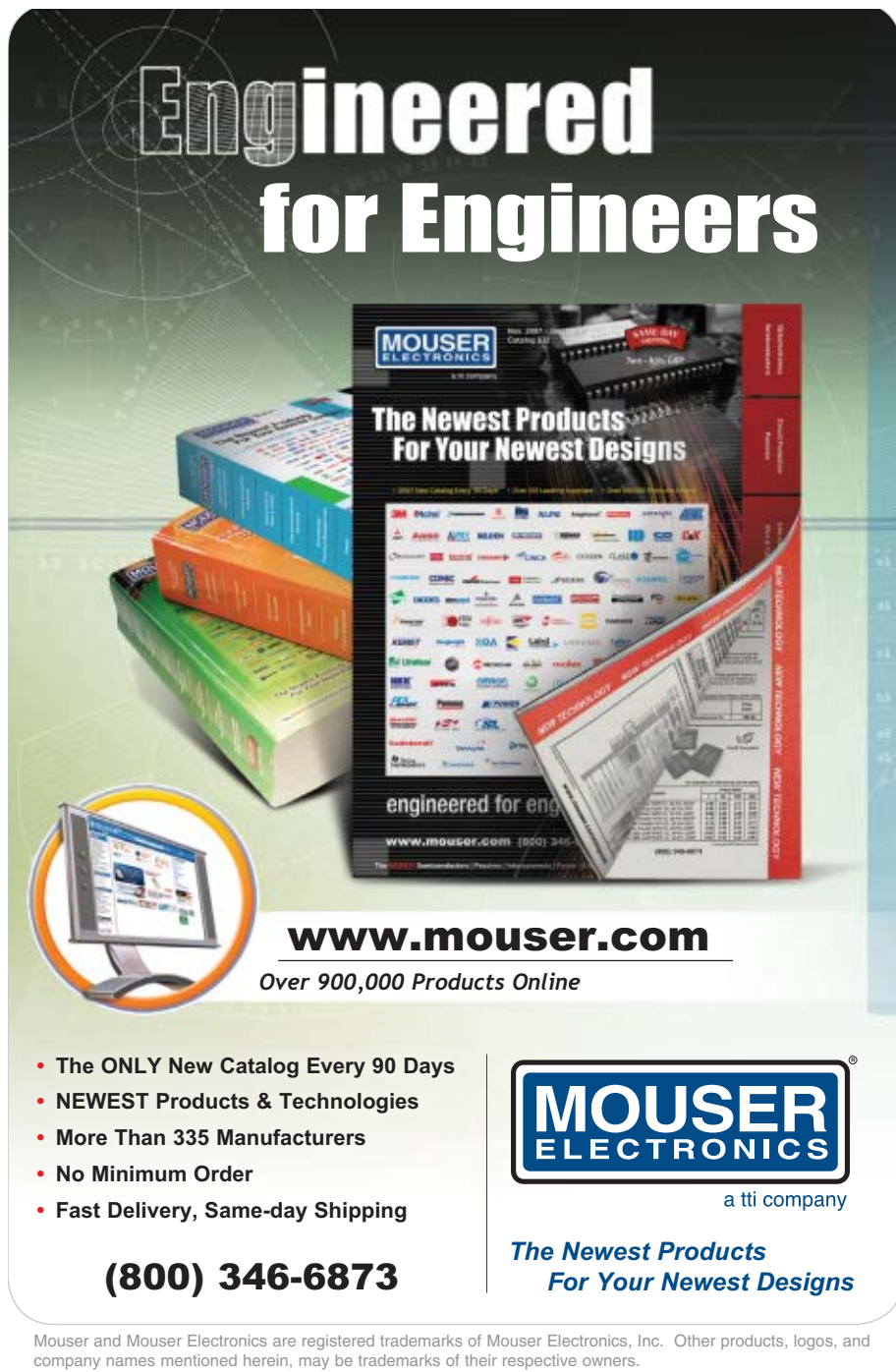
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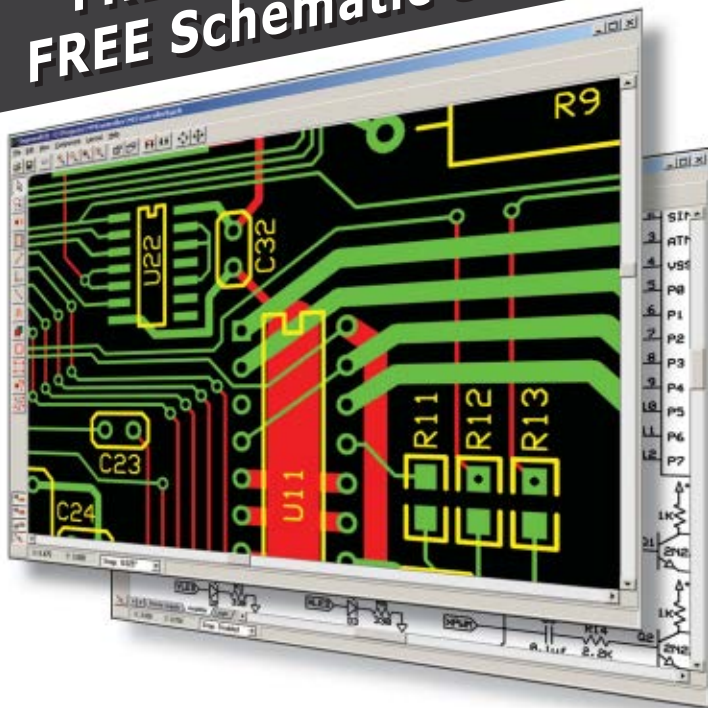
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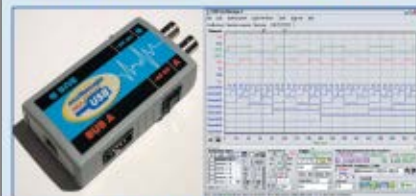
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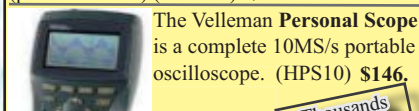


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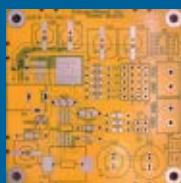
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## ■ THIS MONTH'S PROJECTS

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## ■ LEVEL RATING SYSTEM

*To find out the level of difficulty for each of these projects, turn to our ratings for the answers.*

- . . . . Beginner Level
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**High-power LEDs have received much attention as of late,**

**and jumped in the last few years from a laboratory curiosity into mainstream applications. We all have seen LED flashlights (with their bright bluish white light) and its LEDs incorporated into some luxury auto brands.**

# BUILD A HIGH-POWER LED STROBE

**T**he reason for this rise in popularity is very simple: as light sources measured in lumens per watt, they are extremely efficient. These devices easily surpass incandescent lights, even halogen-filled ones. They also seriously challenge fluorescent and high-intensity discharge lighting (which themselves have undergone extensive efficiency improvements). LEDs offer a few extra features: low voltage operation, small size, and solid-state ruggedness. These qualities make them very attractive for portable and automotive environments.

This doesn't mean that high power LEDs are not without problems. Unlike their lower rated brethrens — which max out at 20 or 30 mA — these monsters start at 300 mA, with 700 and 1,500 mA devices available, and even higher rated devices in the pipeline.

With so much power concentrated into such a small volume, heat becomes a major concern. With the LED itself being a semiconductor, heat substantially reduces both the operating life and the efficiency of the device. Thus, thermal management is paramount in a successful application.

LEDs have an additional advantage that none of the light sources discussed above can match: the ability to be turned on and off almost instantaneously. Only Xenon flash tubes have better response times, but their high voltage has precluded them from being used in applications such as cell phone cameras, where high power white

LEDs have become ubiquitous. As I needed to build a strobe circuit, I decided I should give them a try.

## The Challenges are in the Details

Starting a new project is similar to hiking an unknown trail the first time. One quickly finds unexpected challenges, some of which are tough to solve. But solving those challenges make it all worthwhile, and hopefully, make you a little wiser. This project did not disappoint.

I had originally attempted to build a strobe employing the conventional high-voltage capacitor and Xenon-tube combination — circuits which have been around for a long time — and rapidly noticed the drawbacks. For one thing, it is very easy to exceed the tube's maximum power dissipation at higher repetition rates, causing it to crack. For another, the simple inverter circuits that convert from the battery level voltage to the required high voltage simply do not have enough energy to recharge the flash capacitor in 1/100 second or less. These units are designed for non-repetitive applications, with typical recharge times of two or three seconds — maybe longer — and are two orders of magnitude too weak.

As I pondered how to design the required high power converter, a thought came to mind: This was a perfectly good example for a radical new solution. In this case, employ the newer, high power white LEDs.



■ **FIGURE 1. Light output vs. junction temperature.**

The first challenge was to remove the excessive localized heating which causes a loss of luminous efficiency (shown in Figure 1) and may even set off thermal runaway. Additionally, LEDs are diode junctions, and require their current to be regulated. This is simple, trivial resistor stuff when only a few milliamps are required. Not so trivial — and quite wasteful — when dealing with high currents.

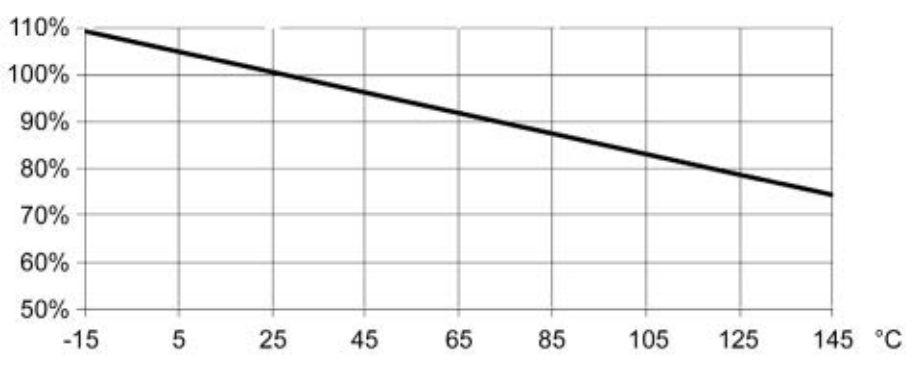
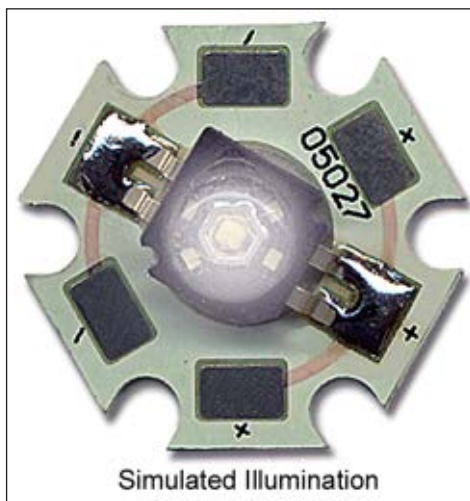
A possible solution would be a current regulated switchmode power supply. However, switchmode supplies do not tolerate excessive current swings, especially when going from zero to full blast and again back to zero in a millisecond. (Hmmm ... who said this would be a simple project?)

To top it all off, these LEDs have a Lambertian light distribution; “Lambertian” being a fancy word meaning “all over the place.” Some sort of lens or reflector would be required to form a useful beam.

First things first ... which LED source should I employ? After reading countless datasheets, I settled for Luxeon’s K2 in a “star” configuration. As shown in Figure 2, the LED die is attached to an aluminum star-shaped plate, which itself is to be mounted to the heatsink. This plate also provides the necessary solder pads to attach the wires.

I quickly determined that an all-aluminum box would both house the project and serve as a heatsink. I could then use hardware (similar to what is used to mount TO-3 transistors) to attach it to the aluminum box. But this hardware caused an interference with the optical lenses. As discussed above, the LEDs require lenses to focus the light, and as shown in Figure 3, these are attached to the LED assembly with an adhesive pad.

■ **FIGURE 2. K2 Star.**  
*Photo courtesy of LuxeonStar.*



A possible solution would be to employ an adhesive thermal compound, but I wanted something that is widely available to hobbyists. A workable solution was found: Apply a tiny bead of silicon thermal compound in the center of the star (on the flat side that will attach to the aluminum box) and push the star firmly against the aluminum box’s face.

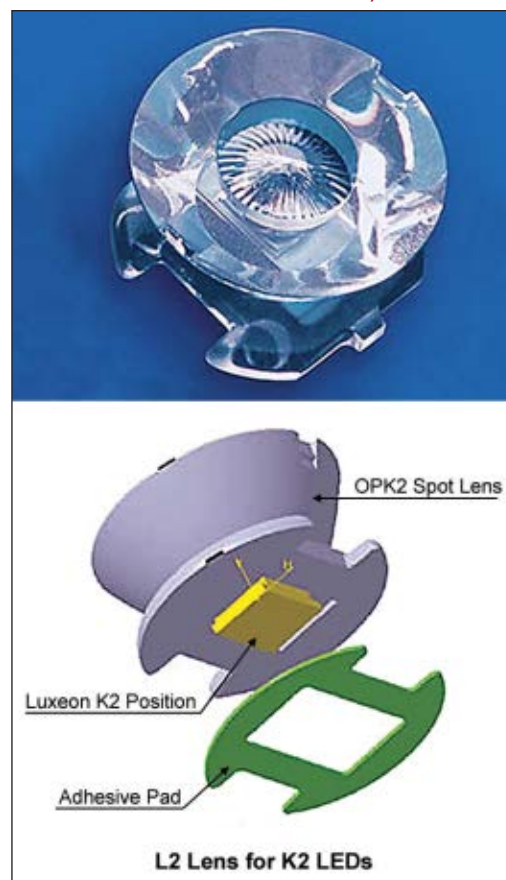
If done correctly, the bead will spread out evenly and NOT smear out. This is important, and it make take a couple of trials to get it right. Then, cyanoacrylate superglue is employed on the star’s periphery to perform the actual bonding. Done correctly, this provides a good thermal interface and fairly secure attachment.

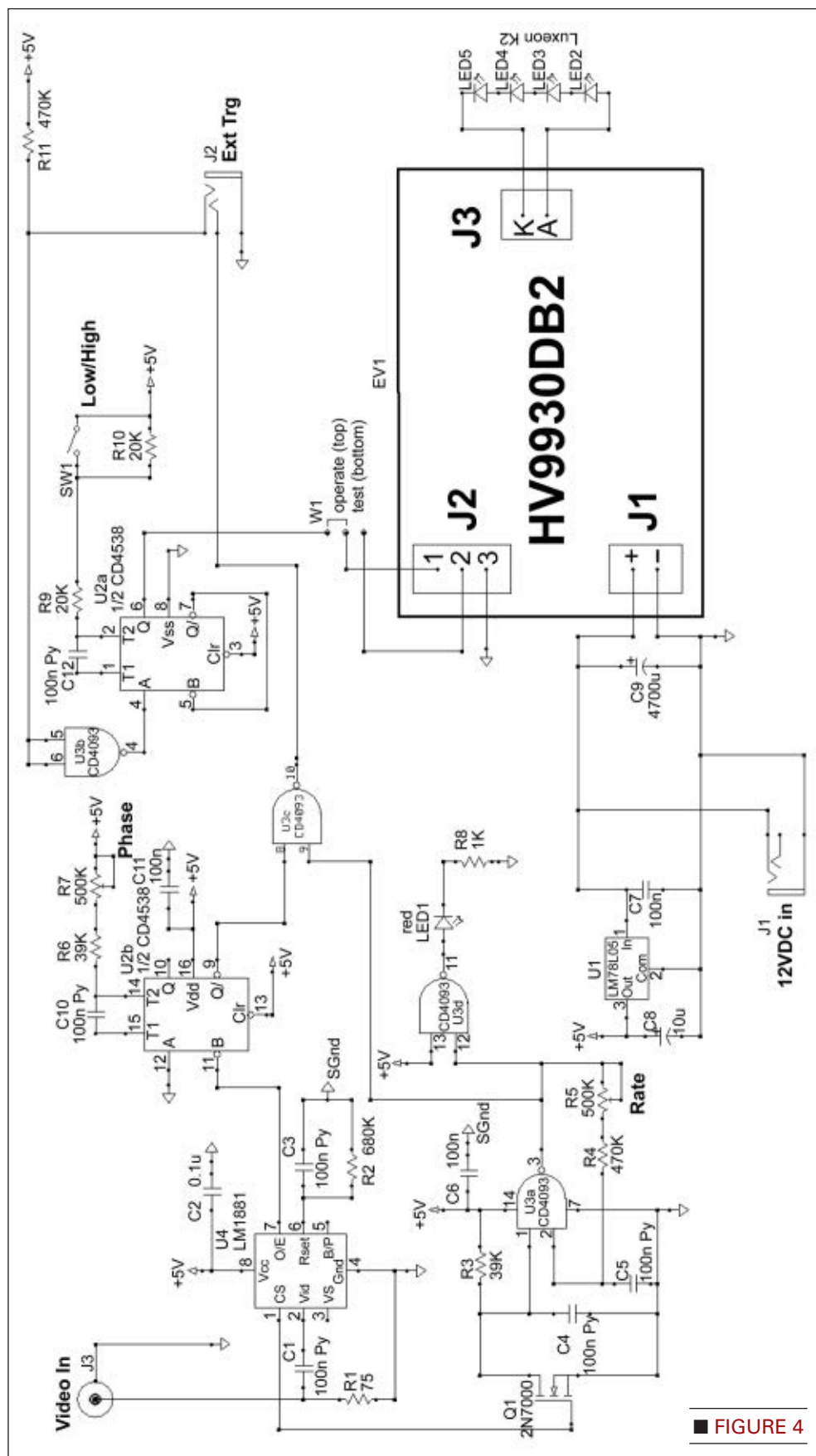
## Electrical Considerations

Having solved the thermal,

optical, and mechanical aspects of the assembly, then came the fun part. How to drive these LEDs? There are literally dozens of high output, constant current switchmode LED drivers available from different IC vendors. However, they either are in nightmarishly-tiny SMT packages, or optimized for steady state output and/or a single light shot such as a flash.

■ **FIGURE 3. Lens assembly.**  
*Photo courtesy of LuxeonStar.*





■ FIGURE 4

As mentioned previously, switchmode supplies respond sluggishly to sudden load changes, which would be the norm for this project. Severe overshoot and ringing usually occur as the control loop attempts to stabilize, which could (in the worst case) cause permanent damage to the unit. There is a control scheme however, known as the hysteretic – or ripple – regulator, which responds the fastest for sudden load changes.

As its name implies, it self-oscillates between two user-set ripple boundaries. Using this search string plus the LED driver, I found a very exciting device from Supertex, Inc. The HV9930 feature set not only satisfied the hysteretic current control scheme, but it also employs the Cuk (buck-boost) powertrain topology, meaning that the output voltage may be higher or lower than the input voltage for increased versatility. It also drives an external MOSFET, and thus its output drive may be as large as required, depending on the external device ratings.

The device is available in both eight pin thru hole and SMT packages. It is available through Mouser – important since all the wonderful specs are meaningless to a hobbyist, if the device is only sold through a distributor network which caters to small orders.

Better still, the device has an available plug-and-play evaluation board (HV9930DB2), which is a major plus if one doesn't have the time or inclination to design a switchmode supply from scratch. The board has a quick responding enable input which can be used for either PWM dimming, or in this case, for pulsing.

One last consideration when employing this module is that it has a minimum eight volts DC input requirement, with 12 volts DC preferred. This is okay, since the high power requirements



demand much more juice than what four AA cells can realistically provide.

The evaluation board is preset to 750 mA, which dictates that 700 mA grade stars be used. I would have liked to use 1,500 mA stars, but that means substantial EV board modifications, which are beyond the scope of this article.

### Control Circuit Description

I had some goals for the control circuit: It should be capable of driving the HV9930 evaluation board from three different trigger sources: component video to synchronize with a camera; an external open collector or TTL level signal; and an internal variable frequency oscillator. It must also have calibrated power levels achieved by precisely controlling the light pulse's output width. The schematic is shown in Figure 4.

A +12 volt DC external source is fed via J1 to both the evaluation board EV1 and a five volt regulator U5 that feeds the control circuit. Capacitor C9 should be located very close to EV1, to smooth out the demand for high current pulses.

An external NTSC/PAL video component signal is applied to J3, with resistor R1 providing the proper termination impedance, and is fed via C1 to sync separator U4. This IC has many functions, but we are using only two: The composite sync output is employed to turn on MOSFET Q5, which discharges capacitor C4. This low voltage applied to NAND gate U3a disables it from oscillating when a valid video signal has been connected. Another of U4's functions — the Odd/Even field output — is employed.

A little explanation is required here. Individual TV images — or frames — are comprised by two interlaced fields, which each include the odd and even scan lines. Modern video sensors capture the entire frame simultaneously, but to comply with this legacy TV standard, the signal is processed and interlaced before sending it to the video output. For the

purposes of this project, this would create double light pulsing while the frame is acquired, causing a double exposure. The Odd/Even output effectively chooses a single field, synchronized to the video capture. Since the CCD's actual frame capture timing (with respect to this signal) is unknown, we must delay its phase such as both coincide. This is achieved by monostable U2b, which is triggered on O/E's falling edge.

The phase delay is set via C10, R6, and potentiometer R7. By adjusting the latter, the light pulse can be made to coincide with the actual video capture. This can easily be accomplished empirically: One turns R7 fully to one end, and then start backing up slowly until the image on the camera's viewfinder becomes the brightest.

Both the composite sync and O/E outputs become a logic low when a video signal is absent. This has two effects; first, U2b is no longer triggered and no further pulses occur. Second, Q5 is no longer turned on, and C4 charges through R3. When a logic high is reached, U3a is allowed to oscillate via positive feedback via R4 and R5, and in conjunction with C5, sets the frequency. This is coupled to U3c which is no longer receiving pulses from U2b, which serves to select which pulse (video or free run) passes through.

In essence, all this circuitry selects a free running pulse when no video is available, and a field synchronized pulse when a valid video signal is present. U3d only buffers the signal to drive a small red LED, which indicates oscillator activity.

The selected signal goes to the normally closed contact of "external trigger" jack J2. When no plug is connected, the signal will continue to U3b and then to the next monostable U2a. The reason for employing U3b is to provide a Schmitt-Trigger action for the external signal, which provides noise immunity and the fast trigger edge

required by U2a. This monostable is wired in a non-retriggerable configuration, to prevent pulsing stretching due to noise.

The external trigger may be either a TTL-compatible square wave, a switch, or a transistor closure to ground. In this last instance, R11 serves as a pull-up.

The pulse width is selected by switch SW1 and associated components C12, R9, and R10. This will provide an output pulse duration of either 1/250 or 1/500 second for high or low power mode. This pulse is now applied to LED driver evaluation board EV1 which, in turn, drives the four series-connected Luxeon LEDs.

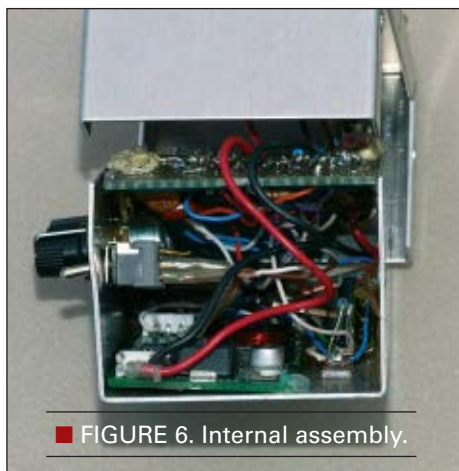
A jumper wire must be installed to select an operating mode: Connecting EV1's pins 1 and 2 together will turn on the LEDs continuously, regardless of any other conditions, and is useful for testing. Connecting EV1's pin 1 to U2a pin 6 reverts the circuit to normal operational mode.

### Assembling the Circuit

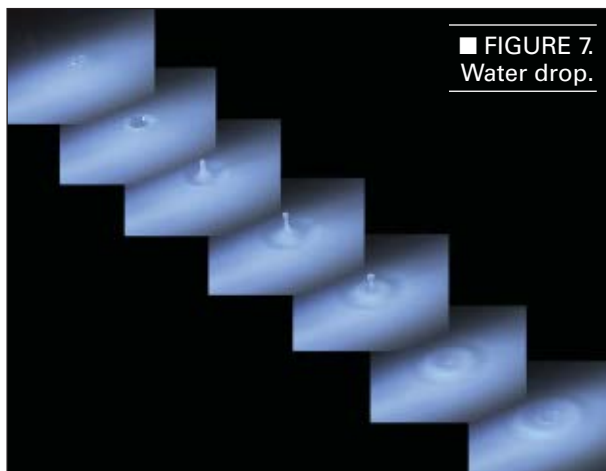
As shown in Figure 5, the whole project is assembled in a small aluminum box. Prior to any electronic assembly, all the holes must be drilled and deburred. Afterwards using a pencil, mark the location of the LED stars, noting the orientation of the plus and minus signs to allow them to be connected in series. Attach them using the thermal compound and



■ FIGURE 5. Completed project.



■ FIGURE 6. Internal assembly.



■ FIGURE 7. Water drop.

lenses to the LEDs. They should sit flat for the adhesive pad to make proper contact. You may find that the soldered wires interfere a little with the placement; use an X-acto knife to remove any small section that gets in the way.

Besides the pre-assembled evaluation board, one must build the control circuit in a separate board. It is simple enough to be built

## PARTS LIST

### ITEM DESCRIPTION

*The following are available through Mouser.*

#### Resistors (all resistors 1/4 W, 5%, unless noted)

- R1 75 ohm
- R2 680K
- R3 39K
- R4,R11 470K
- R5,R7 500K linear pot
- R6 39K
- R8 1K
- R9,R10 20K 1%

#### Capacitors

- C1,C3,C4, C10,C12 0.1  $\mu$ F, 50V, 10% poly
- C2,C6,C7,C11 0.1  $\mu$ F, 50V, X7R ceramic
- C5 0.01  $\mu$ F, 50V, 10% poly
- C8 10  $\mu$ F, 25V, electrolytic
- C9 4,700  $\mu$ F, 16V, low-Z electrolytic

#### Semiconductors

- Q1 2N7000 MOSFET
- U1 7805 voltage regulator
- U2 CD4538 CMOS monostable
- U3 CD4093 Schmitt NAND CMOS gate
- U4 LM1881 TV sync separator
- LED1 Miniature red LED

#### Miscellaneous

- J1 Power jack
- J2 Mini phono jack
- J3 RCA jack
- SW1 Mini toggle SPST switch
- EV1 HV9930DB2 white LED driver board
- All aluminum box 4.0"x 2.2"x 3.0": Hammond 1411FU
- Perfboard, wire, pot knobs, silicon thermal compound, Krazy glue™.

*The following are available from LuxeonStar LEDs ([www.luxeonstar.com](http://www.luxeonstar.com)):*

- LED2-LED5 Luxeon K2 Star, 5027PW12
- L2 spot base 3° lens for LEDs, OPK2-1-003
- L2 spot diffuser 12° sub lens, OPK2-1-012S

superglue techniques described previously. Let them set, but do not install the lenses on the LEDs yet, as they have to be wired in series, carefully observing the polarity.

Now that the LEDs are attached and heat-sunk, wire them to the evaluation board EV1 and power them up. Prepare yourself to be awed at the huge light output, but DO NOT leave them powered longer than a few moments at a time, since the aluminum chassis is insufficient to remove all the heat generated in continuous mode.

Now that you are satisfied with the circuit operation, attach the

using point-to-point wiring techniques in a small perf board. The boards may be assembled and wired as shown in the prototype photo of Figure 6.

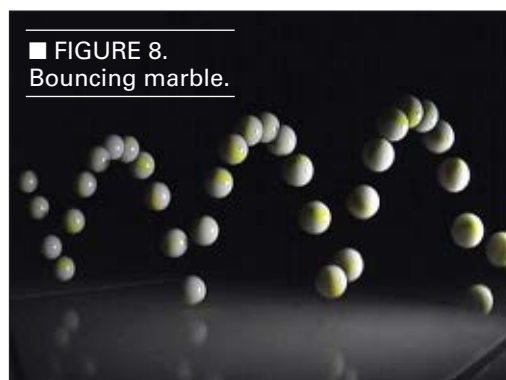
It proved to be a tight and somewhat difficult fit, and I would recommend a larger enclosure for an easier and neater assembly. The recommended enclosure in the parts list is larger than the one in the photo. An extra bonus is the additional heatsinking capabilities.

## Using the Circuit

Strobe lights have long been used by mechanical engineers to study vibrating or rotating elements. By adjusting the frequency fed from a signal from an external oscillator, one can "freeze" the rotational or vibrating movement. Since the oscillator frequency can be measured very accurately, the mechanical frequency may be accurately established, too.

The strobe typically may be triggered upwards of 100 Hz or up to

200 Hz in low power mode, making measurements of 12,000 RPM possible. Be aware of the increased heat generation and a current draw close to 0.5 amps at 12 volts at higher frequencies, both of which decrease linearly



■ FIGURE 8. Bouncing marble.



with operating frequency.

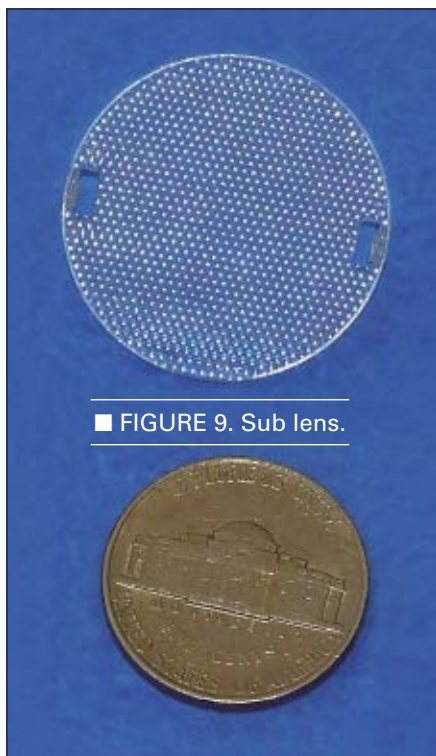
Although the light output is necessarily low power — because of its repetitive nature — compared to a one shot Xenon flash, the circuit may still be used for some photography tricks. In this instance, the video input comes in handy.

Connecting the composite video signal from a camera will synchronize the flash to the actual frame capture. As described previously, you may need to adjust the “Phase Delay” control to obtain maximum brightness, as observed in the viewfinder.

The water drop sequence in Figure 7 and the bouncing marble in Figure 8 were obtained employing this technique.

You may find that the LED lenses produce a beam that is perhaps too narrow ( $\pm 3$  degrees) for practical photography usage. Fortunately, the sub lens shown in Figure 9 (that attaches to the top of the main lens) will widen the beam to  $\pm 12$  degrees.

Finally, the project may be used in the free run mode, much like the disco strobe lights so popular in the '70s. So, load your favorite funky music CDs and enjoy! **NV**



■ FIGURE 9. Sub lens.

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## Tropical Depression Ernesto sparked my desire for emergency lighting

when gale-force winds knocked out my family's electricity for 45 minutes on the evening of September 2, 2006 as its remnants moved north past our home on the Delmarva Peninsula. After the initial whines and complaints about the power outage from our two teenagers, my wife and I distributed flashlights, a deck of cards, board games, and a battery-operated radio to them. Then we sat back on the couch, listened to the radio, and watched our kids play cards by flashlight on the living room floor. It turned out to be a very pleasant evening, and I was almost sorry to see the power come back on.

# MODIFICATION OF A SIX VOLT LITHONIA EMERGENCY LIGHT

## For Night Use Only

**S**hortly after Ernesto blew through, I obtained an emergency light (see Figures 1 and 2). I mounted it on the wall in my kitchen and plugged it into a nearby power outlet. This arrangement allows one lamp to illuminate the stovetop and the other lamp to shine out into the living room; problem solved, or so I thought ...

### A Mid-afternoon Power Failure

I was reading a book by the sunlight shining through the windows on March 14, 2007 when I experienced the next power failure. The lights, television, scanner, and computer were already off, so I had

no way of knowing the power had gone out — except the emergency light shining in my face unnecessarily. Four thoughts flashed through my head as the light struck my eyes:

- I didn't know why the power had gone off, or how long it would be off.
- Lithonia designed this device to provide light for no more than 1-1/2 hours.
- Sunset was 4-1/2 hours away!
- I had to do something — and soon — or the battery would be dead at sunset if the power was still out.

I quickly rigged an extension cord to the emergency light from the small 12-volt inverter I keep in my truck. I wanted to maintain the charge on the emergency light's battery, and I wanted to provide power to my scanner so I could find out what had caused the outage by tuning in to EMS and the power company's radio communications. The power company restored power after only 20 minutes, but I had already concluded that I needed to add a

■ FIGURE 1



■ FIGURE 2



circuit to the emergency light that disabled the lamps and prevented the battery from discharging during the day.

## Circuit Analysis

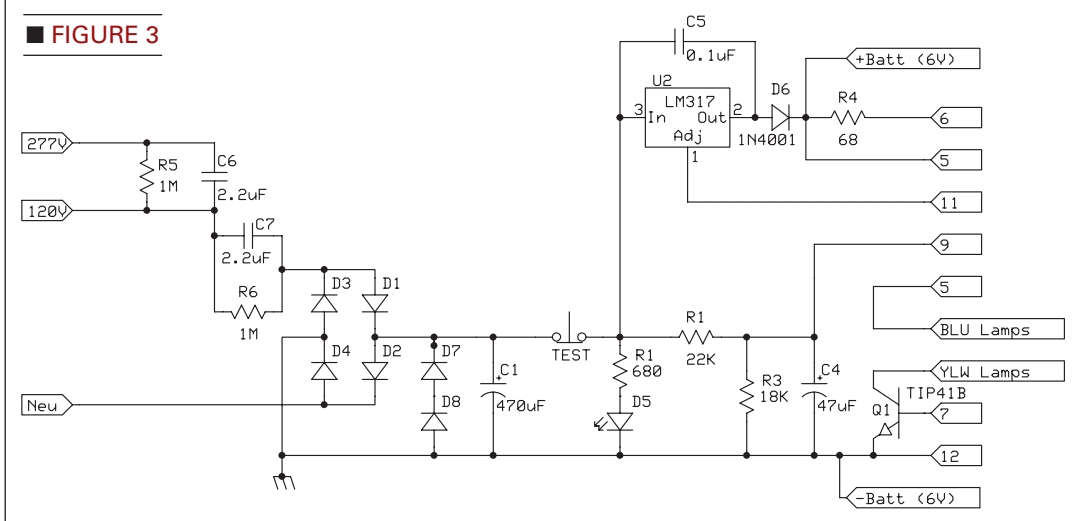
### Lithonia 6V Emergency Light (EMEPD00114 Rev.A)

A “Portalac” 6V, 4.5 AH, sealed valve regulated lead acid battery is the emergency light’s primary power source. A 120/277 VAC power supply maintains the battery’s charge. A parallel RC network in series with the bridge rectifier drops the line voltage to 15.65 VAC. A 470  $\mu$ F 35V electrolytic capacitor filters the output from the rectifier, and an LM317T adjustable voltage regulator in a TO-220 package regulates the filtered DC voltage (see Figure 3).

A custom integrated circuit packaged in a 14-pin DIP performs multiple functions. The chip’s onboard battery charger monitors the battery voltage when AC power is available and adjusts the output voltage of the LM317 for optimum charging based on the battery’s state of charge. A low-voltage disconnect circuit monitors the battery voltage during a power failure and shuts off the lamps to prevent damage to the battery from excessive sulfation of the plates. A power failure detection circuit monitors the presence of AC power and switches the lamps on and off.

My search for the “light switch” turned up a TIP41 NPN bipolar transistor in a TO-220 package that the signal from pin 7 of the IC controls. It is in a series circuit with the lamps and the battery. The lights switch on when the output of pin 7 is 6 volts, and they switch off when the signal from pin 7 falls to 0 volts. I

■ FIGURE 3



needed to tap into this signal for my brainchild to work, and this would involve minor “bypass surgery” on my part.

First, I cut the circuit board between the base of the light switch transistor and pin 7 of the control chip with a 1/16” drill bit (see Figure 4). Next, I scraped the light green insulating film from the copper circuit board traces and soldered a four-conductor ribbon cable from the freshly exposed traces, the 6V trace, and the ground trace to the daughter-board I would construct (see Figure 5).

### Electric Eye

The schematic for the Electric Eye

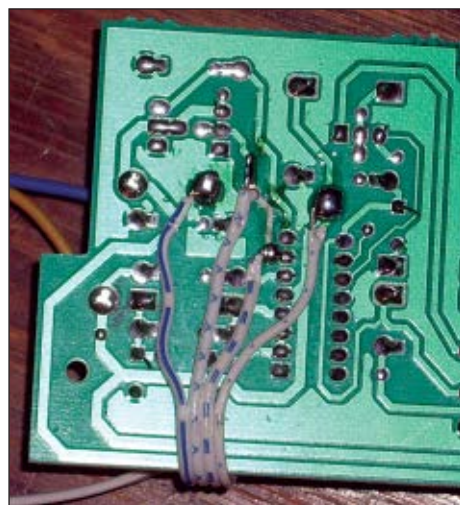
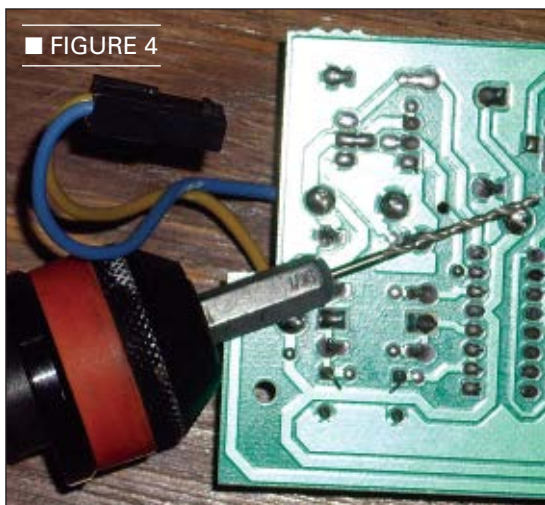
## LITHONIA'S CONTROL IC FUNCTIONS

- Pin 5 — 6 volt supply
- Pin 6 — Battery voltage feedback input
- Pin 7 — Light switch control signal output
- Pin 9 — AC power failure detection input
- Pin 11 — Voltage regulator control output
- Pin 12 — Ground
- The other pins are unused or their use could not be determined

option is shown in Figure 6. The cadmium-sulfide photoresistor voltage divider provides an analog signal of the ambient light level to the non-inverting input of the 741 operational amplifier. The value of the fixed resistor that forms the other

■ FIGURE 5

■ FIGURE 4





### AND Truth Table

A	B	X
No	No	No
No	Yes	No
Yes	No	No
Yes	Yes	Yes

### OR/NOR Truth Table

A	B	OR (X)	NOR (X)
No	No	No	Yes
No	Yes	Yes	No
Yes	No	Yes	No
Yes	Yes	Yes	No

### NOTed NOR gate = AND gate

A	B	X
Yes	Yes	Yes
Yes	No	No
No	Yes	No
No	No	No

circuit described next. The LED conducts when the output voltage of the op-amp rises above the LED's forward voltage. This allows enough base current to turn on transistor "A" in the inverter (logical NOT gate) circuit.

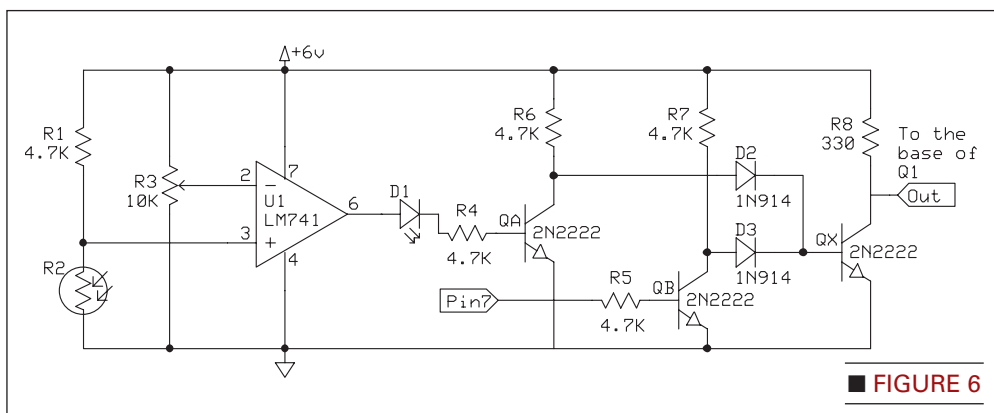


FIGURE 6

### Digital Logic Circuits

Digital logic circuits receive signals that represent the two binary digits 0 (NO/OFF) and 1 (YES/ON). A voltage of six volts represents a YES signal, and a voltage less than two volts represents a NO signal. Here's how the individual components work. Think of the emitter and collector terminals of a transistor as the terminals of a pushbutton switch

and the base terminal as the switch's button. A YES signal presses the button by allowing current to flow through the transistor's base-emitter junction. This causes the transistor to conduct electricity through the emitter and collector terminals. A NO signal releases the button and the transistor returns to a non-conducting state. This is a highly simplistic version of how a transistor operates, but a more accurate explanation that delves into the physics of semiconductors is beyond the scope of this article.

Input transistor A receives a signal from the op-amp to answer the question, "Is it dark?" Input transistor B receives a signal from the Lithonia IC to answer the question, "Has the AC power failed?" If the answers to question A and question B are YES, then the logic circuit's output X responds with a YES and turns on the light switch transistor (Q1) on the emergency light's main circuit board. A logical AND gate circuit fulfills the requirements of this application.

The 741 functions as a voltage comparator in this application. When the voltage across the photoresistor falls below the voltage set at the inverting input of the op-amp by the

leg of the voltage divider needs to be determined experimentally because it will depend on the light and dark resistance values of the CdS photoresistor you select for this application. I found that aiming the photoresistor at a white ceiling obtains an accurate indication of the ambient light level.

As the light on the photoresistor brightens, the resistance falls and the voltage across the photoresistor (and at the non-inverting input of the op-amp) drops. On the other hand, as the light on the photoresistor dims, the resistance rises and the voltage across the photoresistor increases.

The 741 functions as a voltage comparator in this application. When the voltage across the photoresistor falls below the voltage set at the inverting input of the op-amp by the

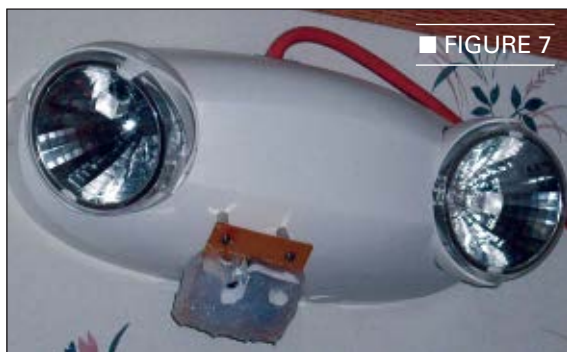


FIGURE 7

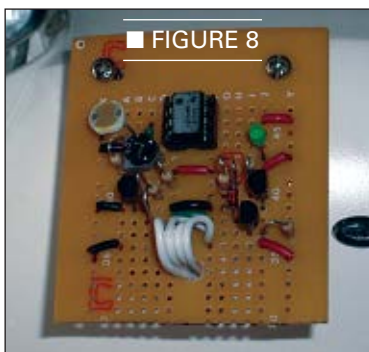


FIGURE 8

### Diode-Transistor-Logic

The diode-transistor-logic (DTL) circuit in Figure 6 functions as an AND gate, but the actual logic circuit I used is defined as a NOTed



NOR gate. Transistors A and B function as logical NOT gates for each input. The two 1N4448 diodes function as the two-input OR gate, and transistor X functions as the logical NOT gate on the output. By inverting the inputs of the NOR gate, we effectively end up with an AND gate.

I will walk you through all four possible scenarios that the AND gate will encounter. In the first three scenarios, the answer to "Is it dark?" is NO or the answer to "Has the AC power failed" is NO. Base-emitter current will not flow through the transistors if their inputs are NO. This keeps the voltages at their respective collectors high enough to allow current to flow through one or both diodes and the base-emitter junction of transistor X. The collector voltage of transistor X stays close to 0 volts and keeps the light switch transistor (Q1) off.

In the final scenario, the answer to both questions is YES. Both transistor A and transistor B are conducting, both collector voltages are close to 0 volts, and base-emitter current from transistor X cannot flow. The collector voltage of transistor X is high enough to allow base-emitter current to flow from the light switch transistor (Q1) on the main board and switch on the lights.

## Mounting the Daughterboard

Always disconnect the AC power before working on this project because the emergency light lacks a power isolation transformer. Therefore, mounting the daughterboard inside the plastic cabinet of the emergency light is preferable to mounting it on the outside of the cabinet.

However, I chose to mount it on the outside of the cabinet, anyway. I drilled an offset hole in the circuit board adjacent to one of the original mounting holes to allow for the emergency light's curvaceous cabinet (see Figure 7). This reduced the strain on the circuit board.

My primary reason for mounting on the exterior was the limited amount of space available inside the

## PARTS LIST

ITEM/DESCRIPTION	PART #	QTY
□ D1 – 2.2V 20 mA 3 mm green LED	253665	1
□ D2, D3 – 1N4448 diodes 100PIV 0.2A	655242PS	2
□ R1, R4-R7 – 4.7KΩ 1/4 watt resistors	691024	5
□ R2 – Cadmium sulfide photoresistor	202403	1
□ R3 – 10KΩ trimmer potentiometer	254203	1
□ R8 – 330Ω resistor 1/4 watt resistor	690742	1
□ IC1 – 741 operational amplifier	24539	1
□ QA, QB, QX – 2N2222 NPN transistors	28629PS	3
□ Circuit board standoff mounts	393895	2
□ Eight-pin DIP socket	683104	1

A 2-1/2" x 2-1/2" circuit board will hold all of the components for this project. RadioShack may have most of the required parts, but Jameco has a wider selection and lower prices if you are willing to pay for shipping and wait for the delivery of the parts. All part numbers listed are from Jameco.

cabinet. The second reason is that I sealed the circuit board's components (with the exception of the CdS photoresistor, the 10K ohm potentiometer, and the LED) in silicone caulk for electrical insulation. I used stiff postcard material to construct crude molds around the components

that I did not wish to seal off from the outside world. It took the caulk between two and three days to set (see Figure 8). Third, I mounted the emergency light too high for curious and untutored hands to reach. Finally, and most importantly, I wanted to place my creation on display. **NV**

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Here's a simple circuit I came up with as part of another project I was working on to measure the acceleration of a model rocket in flight. While my original data storage requirements for that project were very specific (and very basic), I realized that the datalogging circuit and code had many other uses.

**This datalogger is suitable for just about any application**

where a small, cheap, low power circuit is needed to sample analog voltages, convert them to digital values, and store a modest amount of data in non-volatile memory.

# SINGLE CHIP, FOUR CHANNEL DATALOGGER

The circuit shown in Figure 1 is based on a Microchip PIC16F876A microcontroller. This chip has a built-in, five channel 10-bit analog-to-digital converter (ADC), but only four channels are shown being used. It is very simple to modify the code to use from one to all five ADC channels (more on this later).

A linear voltage regulator (such as the LM78L05) powers the PIC and any five volt tolerant sensors which may be added to the circuit. One mode-select jumper is used to place the microcontroller in data acquisition mode or in "data dump" mode. An in-circuit serial programming (ICSP) header is included to reprogram the PIC after the circuit has been assembled, along with a diode to prevent the programming voltage from getting into the rest of the circuit via the five volt bus.

The 876A contains three different types of memory: 368 bytes of RAM, 256 bytes of EEPROM, and 8,192 words of Flash program memory. There isn't enough RAM or EEPROM for serious data storage, and the Flash memory is for the program code, so where can our data go?

Well, if we are very careful, we can use the WRITECODE and READCODE instructions in PICBASIC PRO (available at [www.melabs.com](http://www.melabs.com)) to store that data in the Flash program memory. The code listing (available at [www.nutsvolts.com](http://www.nutsvolts.com)) only uses about 400

words of program memory. That leaves nearly 7,800 words for data storage; enough to capture more than 1,900 samples of the four 10-bit ADC values.

The code starts out by defining variables, and the most important of these is the "pointer" variable. This defines the address in the Flash memory at which the data will be written during data acquisition. The initial value of this variable is set at an address beyond the last word of program code, so there is a bit of unused memory between code and data. If you modify and recompile the code, you must check how many words your new code occupies and adjust the initial pointer value accordingly to make sure your data cannot overwrite your code.

Next, the code checks the status of the mode select jumper on pin RA4 and jumps to either the data acquisition loop or the data dump loop. The two loops are very similar in structure, using the same variables to cycle through the ADC channels and either write to or read from the Flash memory. Each loop is terminated with an END command, so that when all of the memory has been written or read, the PIC will enter a power-saving sleep mode.

The number of ADC channels used is determined by the "channel" variable, which is used to set the number of times the ADCIN command is executed in each pass through the data acquisition loop.



As mentioned earlier, the maximum value for this variable can be anywhere from 1 to 5.

A datalogger isn't much good without some sort of time reference associated with your data. The code provides a relative time stamp for each set of data through a pause command, which is calibrated to provide the desired delay between data acquisitions. This calibration is accomplished using the "test pulse out" signal on pin RB1 and an external frequency counter.

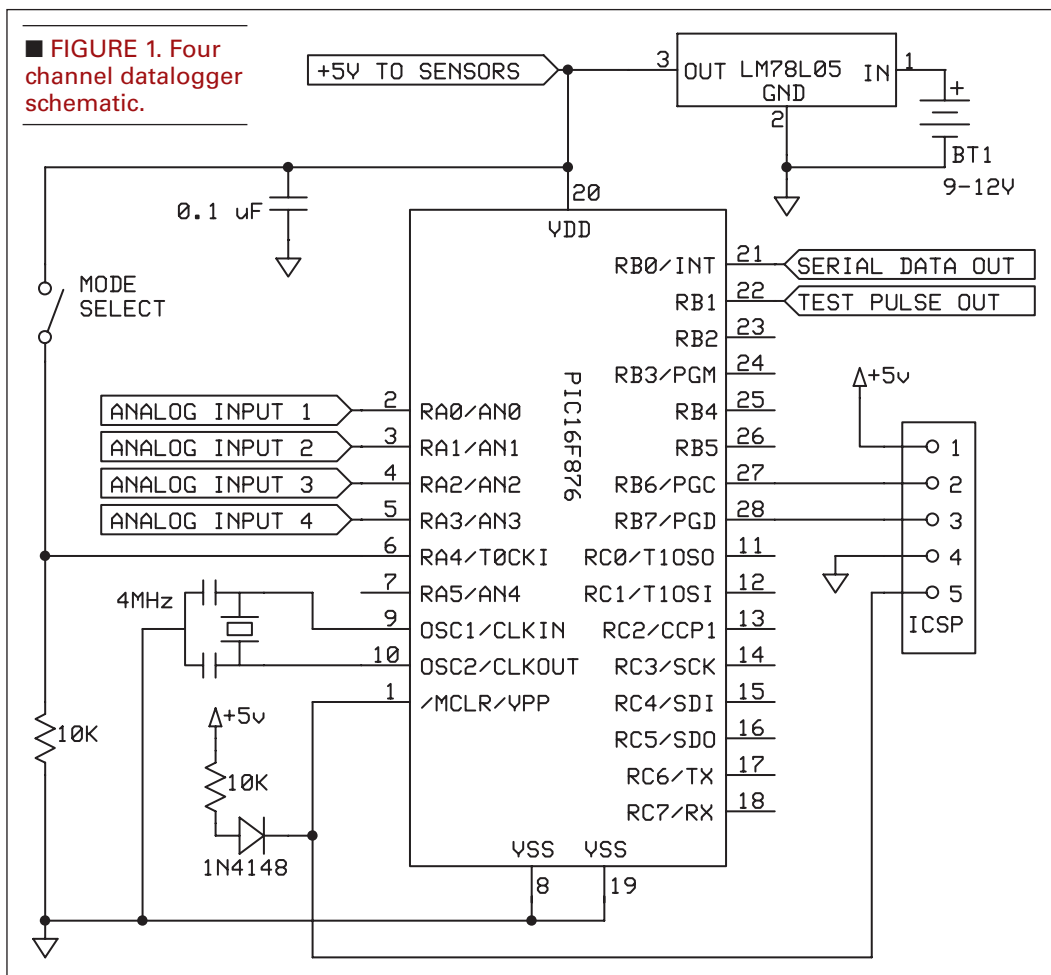
The code as written will collect data every 0.1 seconds using a pause value of 94 milliseconds, as near as my frequency counter could resolve. A pause value of 994 milliseconds should give a one second interval between data acquisitions, and so on. Remember to recalibrate this pause interval whenever you make changes to the code in the data acquisition loop.

Once your datalogger is full, power it down and connect it to a standard serial (not USB) port. Only the receive data and signal ground pins on the computer's serial port need to be connected.

The computer should be running a terminal emulation program set at 2400 baud, no parity, eight data bits, and one stop bit (2400 N81). Also, make sure that the software is not set to use hardware handshaking. It's a bit slow downloading this way – taking a minute or two to dump the whole memory – but this makes it very tolerant of different circuit construction techniques and unshielded data cables.

Before powering up the datalogger, you must install the mode select jumper so the program will begin

■ **FIGURE 1. Four channel datalogger schematic.**



downloading the data. If you don't, the PIC will begin collecting more data and overwriting whatever was there before. The data dump loop formats the data into separate lines for each time reference, with the values in each line separated by commas, starting with the first ADC channel.

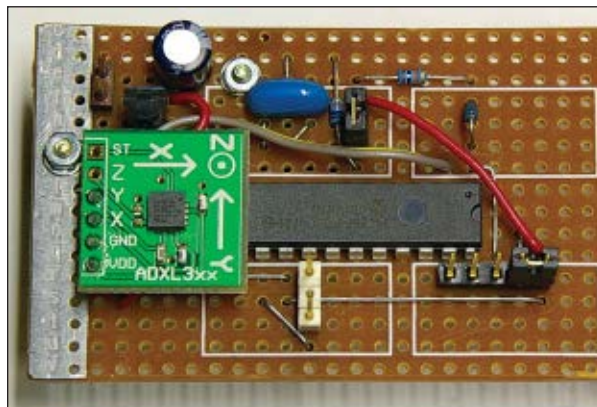
The data can then be easily imported into a spreadsheet in a comma-separated variable (CSV) format, and processed or graphed as needed. Depending on the exact number of data sets recorded, the last line of

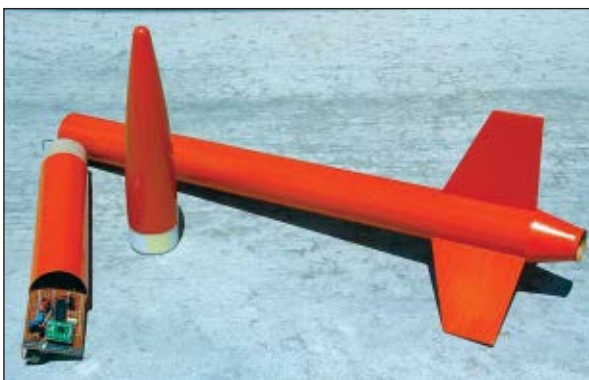
data may contain some invalid values that will need to be ignored.

## Application — Rocket Accelerometer

My rocket-borne implementation of this circuit is shown in Figure 2. I'm

■ **FIGURE 2. Rocket datalogger circuit with two-axis accelerometer daughterboard.**





■ **FIGURE 3.** The datalogger fits neatly inside my launch vehicle.

using an Analog Devices' ADXL321 two-axis evaluation board to measure

the acceleration over the rocket's flight profile. Note the five-pin connection for ICSP, the mode select jumper, and the serial data output

## PARTS LIST

- PIC16F876A microcontroller<sup>1</sup>
- 4 MHz ceramic resonator with capacitors
- LM78L05 five volt linear regulator in TO-92 case
- (2) 10K ohm resistors
- 1N4148 diode
- 0.1  $\mu$ F capacitor
- (2) two-pin and (1) five-pin header

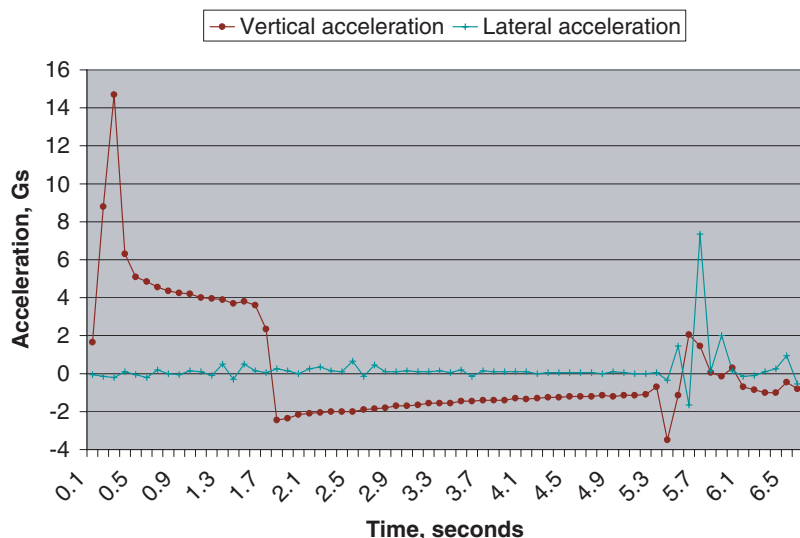
connector (the one with the white base). A 12 V A23 battery in an N-cell holder is bolted to the back of the board, and an additional two-pin jumper is used as an on-off switch.

The circuit layout is non-critical, but all components must be firmly soldered, glued, or otherwise held in

place to endure the stress of launch (the ADXL321 has a range of  $\pm 18$  G, to give you an idea of what I've built it to endure). There are three ADC channels and plenty of board space left for additional sensors.

Have fun keeping track of your world with this datalogger — now there's no excuse for not knowing what's going on! **NV**

■ **FIGURE 4.** Plot of the captured acceleration data during launch and landing (further data available at [www.nutsvolts.com](http://www.nutsvolts.com)).



## CONTACT THE AUTHOR

■ Dan Gravatt can be reached via email at [dgravatt@juno.com](mailto:dgravatt@juno.com).  
<sup>1</sup>A programmed PIC16F876A for this project is available from the author.

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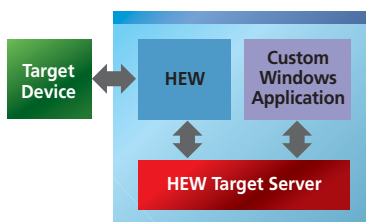
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# Roll the Dice!

## Low-Cost Microcontrollers Enable Electronic “Microdice ( $\mu$ Dice)”

by Marc McComb

A few months back, one of the engineers at Microchip came up with a simple little design using a low-cost, Baseline PIC16F57 microcontroller (MCU). The idea used inexpensive parts such as LEDs and push-buttons to create an electronic dice board, which the engineer nicknamed microdice, or “ $\mu$ Dice.” A basic concept was used for the design — push a button and a value between 1 and 6 is displayed on seven LEDs connected to one of the ports. There is nothing overly complex about the circuit, and the real fun happens when developing the firmware. Recently, I sat down with one of the  $\mu$ Dice boards we made and developed some firmware ideas that are detailed in this article.



### Hardware

First, let’s talk about the hardware involved with this project. The PIC16F57 is a 28-pin MCU with 2K instructions of Flash program memory. The project makes use of the three general-purpose input/output ports (A, B, and C), as well as an eight-bit timer (Timer0).

Taking a closer look at the schematic in Figure 1, the lower two PORTA pins connect to two pushbuttons (SW1 and SW3) that are pulled up to V+. Each pushbutton is used to roll one of two LED die displays connected to PORTB and PORTC. The MCU recognizes a pushbutton press when that particular pin is driven to ground or a logic LOW. RA3 is connected to a buzzer used to generate a clicking sound while the pushbuttons are pressed, to simulate the “shaking” of dice. The remaining pins are

connected as recommended in the datasheet for the PIC16F57.

This application does not require precise timing. Therefore, the MCU uses an RC oscillator by connecting a 10 K resistor and 1,000 pF capacitor in parallel to the OSC1/CLKIN pin (the PIC16F57 will need to be configured for RC oscillator mode in the firmware). SW2 on the schematic connects to the MCLR/Vpp pin. PIC MCUs have the ability to have an externally-triggered RESET generated by driving the MCLR/Vpp pin to ground. On any RESET, the firmware code restarts execution from the beginning.

Finally, notice the P1 header connected to various pins on the MCU. This implements an in-circuit serial programming (ICSP) configuration, which allows the firmware to

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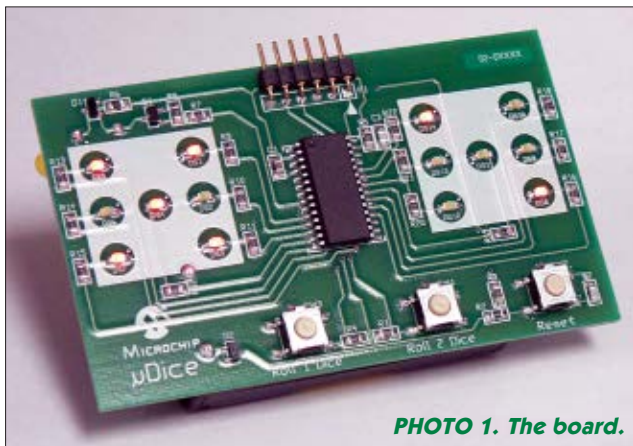
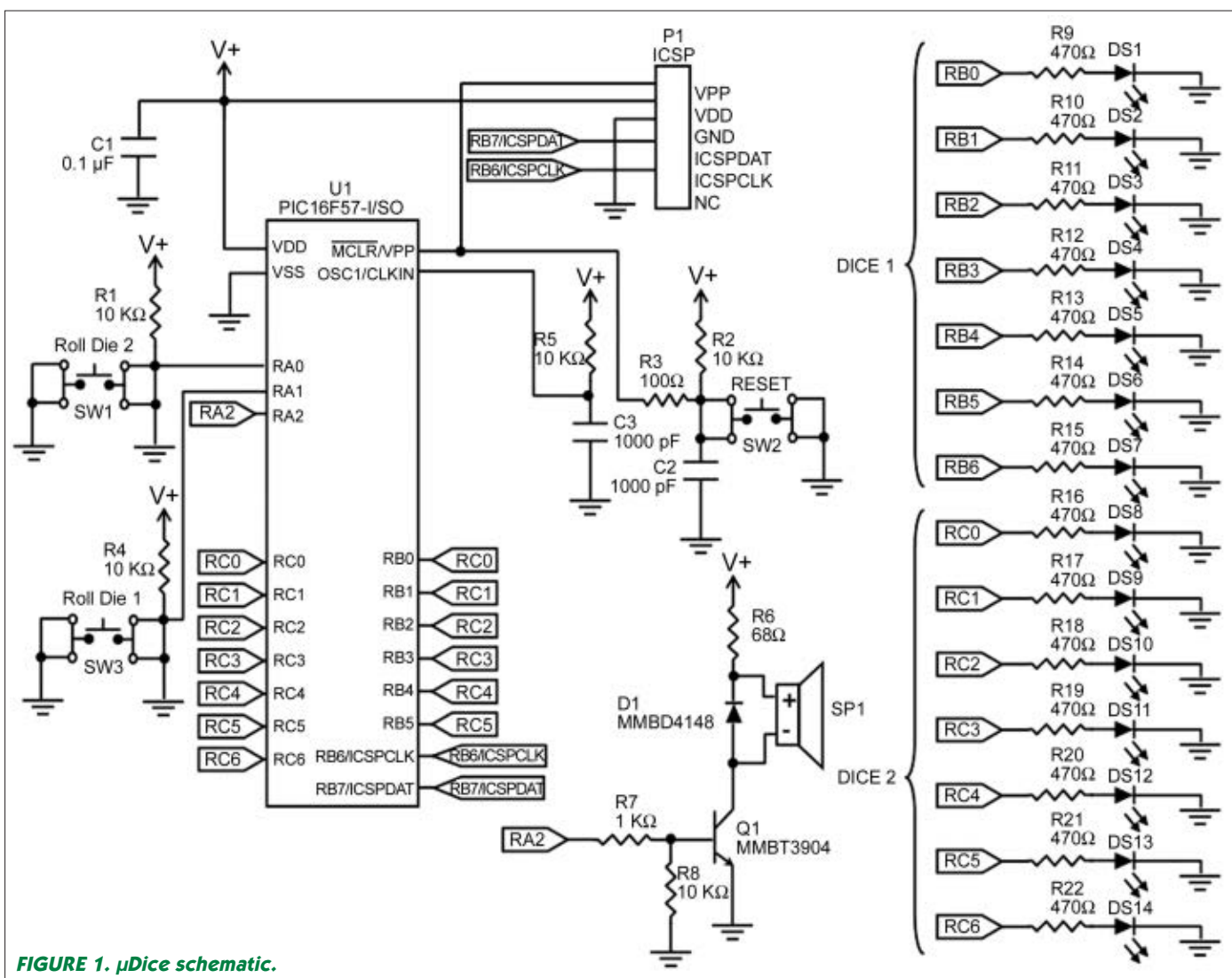


PHOTO 1. The board.





be downloaded to the MCU using the PICkit 2 programmer/debugger.

## Firmware

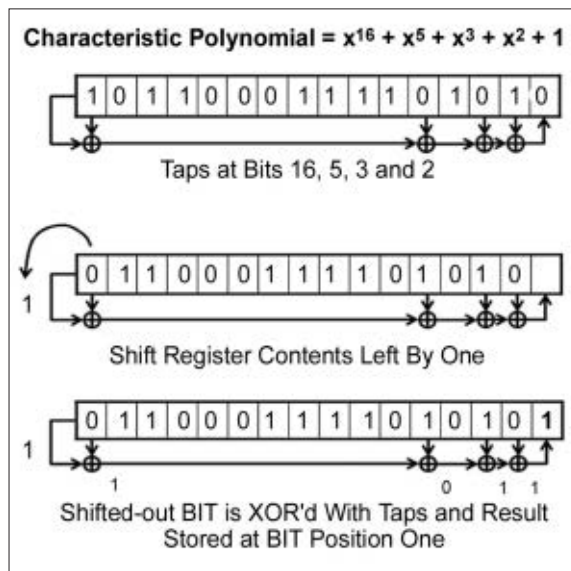
I chose to develop the firmware using the free CCS C compiler that comes with the current free version of the MPLAB® Integrated Development Environment (IDE – available for download at **www.microchip.com/MPLAB**). This allows for the development of firmware written in C directly to the MPLAB IDE. Keep in mind as you read through this article or refer to the firmware that some of the pre-processor directives and functions are compiler-specific and will only work in the CCS environment.

It is a good idea to download the CCS compiler reference manual

from the CCS website ([www.microchip.com](http://www.microchip.com)). This manual outlines all compiler-specific pre-processor directives, as well as a library of functions that can be used to minimize code-development time. I also suggest downloading a copy of the PIC16F57 datasheet from [www.microchip.com](http://www.microchip.com) and keeping it handy, so that you can reference such things as register addresses and control bit manipulation.

As for the code, initializing device/control registers, getting the inputs, and outputting them to

the LEDs is fairly straightforward. The pushbutton states are polled periodically, and a debounce delay is



implemented to eliminate pushbutton contact-bounce issues.

The interesting part of the firmware actually lies in determining the output values to the LED displays. In order to make sure that this dice algorithm produces a truly random result, I decided to use a random number generator (RNG). There are a number of software RNG algorithms out there. In fact, the CCS library includes an RNG function (RAND()). Initially, I did try using this function. However, the code that was generated in the background quickly ate up my data memory. Therefore, a different approach was necessary. I decided to go with what is called a linear feedback shift register (LFSR) algorithm. Figure 2 shows a 16-bit LFSR.

This type of RNG is based off of a "Taps" system that is described by a characteristic polynomial. Each of these tap positions indicates what bit positions within the LFSR itself will be XOR'd with a shifted out bit. Remember how the XOR operation works — if two bits differ (e.g., 1 and 0), then the result is 1. If the bits are the same (e.g., 1 and 1 or 0 and 0), the result of the XOR operation is 0.

As shown in Figure 2, the algorithm starts by shifting the LFSR bit by bit. The shifted-out bit is then XOR'd with the new value at bit position 16, since this is where a tap is located. The result of that operation is then XOR'd with the next tap at bit position 5 and so on, to the tap at bit position 2. The one-bit result of all these XOR operations is placed at bit position 1 and the process starts over.

Repeatedly performing this operation should generate seemingly unpredictable, subsequent values in

the LFSR. This LFSR style of RNG is an example of a pseudo-random number generator. This means that, if scrutinized closely enough, one would observe a definite pattern in the sequence of values generated. The trick here is to make these values seem to occur randomly.

An idea 16-bit RNG should generate  $2^{16} - 1 = 65535$  values before repeating a value (not counting zero). The secret is to make sure that a characteristic polynomial of maximal length is chosen. Maximal length simply means a tap sequence that will generate the longest possible run of sequential values, before the sequence repeats itself.

Some basic rules are applied to selecting a maximal length characteristic polynomial:

1) There should be an even number of taps.

2) The polynomial should be relatively prime and irreducible (the polynomial cannot be further reduced).

I chose the polynomial and tap sequence shown in Figure 2. To implement this in software, I first declare a 16-bit integer variable named LFSR and initialize it to 1. I realized I needed to save the most significant bit before the register is shifted so that it can be XOR'd with bits located at the tap positions. This is accomplished by declaring a one-bit variable of type int1 named Output\_bit. To identify the tap locations, the #bit directive is used to name individual bit locations in the LFSR as follows:

```
#bit LFSR_16 = LFSR.15
```

Why am I assigning LFSR.15 (bit 15) to LFSR\_16? This is to avoid

confusion in the code. Different bit numbering conventions are used between the characteristic polynomial and the compiler. The compiler (and PIC16F57 datasheet) identifies a 16-bit register as bits 0-15, while the polynomial identifies these same bits as 1-16. The randnum\_generator() function performs the LFSR algorithm to generate each value as follows:

1) First, the 16th bit of the current value in the LFSR variable is saved to the Output\_bit variable.

2) The contents of the register are then shifted left by one.

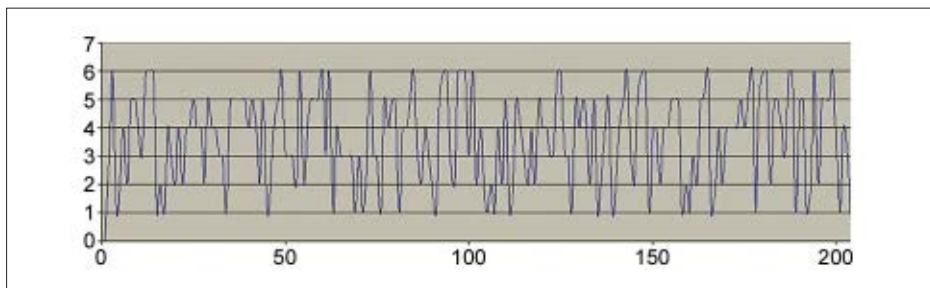
3) The Output\_bit is now XOR'd with the new contents of LFSR to generate the least significant bit in the register as follows:

```
LFSR_1 = (((Output_bit ^ LFSR_16) ^ LFSR_5) ^ LFSR_3) ^ LFSR_2);
```

4) If at some point the LFSR register is filled with zeros, the XOR operation will no longer work, and the algorithm will fail and produce an endless series of zero values. Therefore, this condition will need to be taken care of using a conditional IF statement to reseed the LFSR with decimal 1 to restart the sequence.

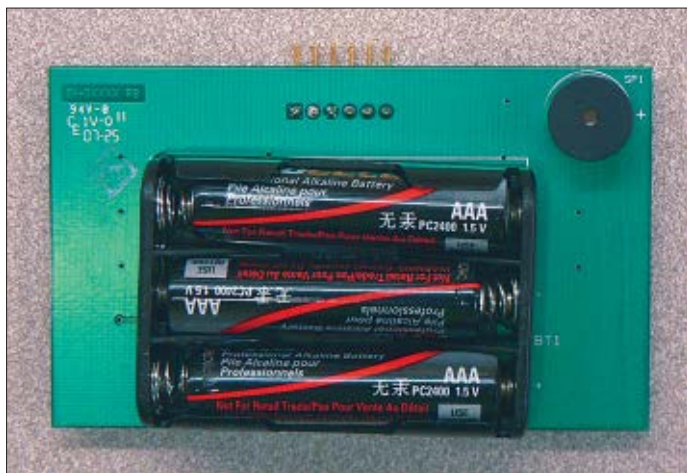
```
if (LFSR == 0b0000000000000000)
    LFSR = 1;
```

The randnum\_generator() executes immediately on any RESET or power-up and continues to execute, so long as the MCU has power. This idea stems from the basic operating theory of slot machines. A slot machine constantly runs a RNG while there is power to the machine. Once the user hits a button or pulls a lever, the current random number is stored, compared against a table of possible output combinations and the result displayed accordingly. Using this basic methodology, as long as the dice application is running, a random number is generated.



**FIGURE 3. Excel-generated graph of sequential contents in LFSR register.**





**PHOTO 2. Back view.**

As soon as one of the pushbuttons is pressed, the current value in the LFSR is stored and used to generate an output.

A mod by 6 operation is performed on the saved LFSR value (i.e.,  $LFSR \% 6$ ). This divides the contents by six and discards all other information, except for the remainder. For example, if the LFSR value is 35, moding by 6 produces a remainder of 5. Likewise, moding 30 by 6 produces a remainder of 0. The result of the mod operation is used to select one of six values stored in a  $1 \times 6$  array called `DIE[6]`. The array holds the predefined values that will be used to set or clear individual port pins to light the appropriate LEDs, according to the determined dice side.

## Testing the Random Number Generator

To test how random the values generated by the `randnum_generator()` are, I implemented the Stimulus tool using the SIM simulator within the MPLAB IDE. In the Stimulus window, there are a number of options. The "Register Trace" option enables you to take subsequent contents of a register in data memory, and store them into a .txt file during a simulation.

In order to ensure that only the values you want are written to the .txt file, a tag will be needed. Basically, what you want to do is create a dummy function that contains no

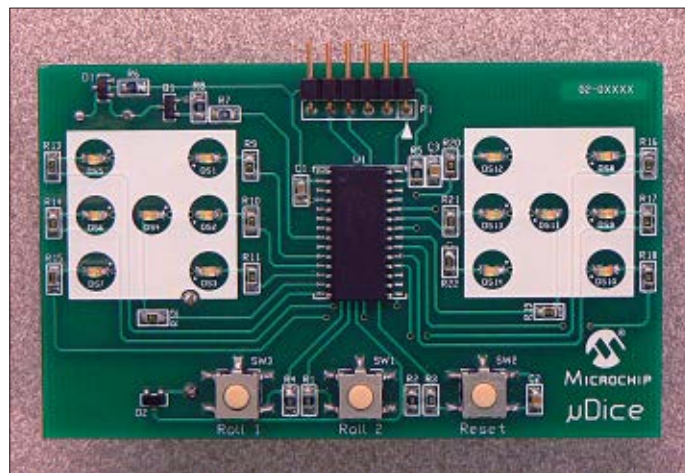
code. Call the dummy function just before the variable register value you are interested in changing. Setting the dummy function as the Program Counter (PC) value (in the Register Trace window) denotes when and what to write to the .txt file. At the end of the simulation run, this text file can now be imported into a spreadsheet application (such as Microsoft Excel) and graphed.

The resulting graph for the LFSR RNG used in this application is shown in Figure 3. Clearly, this is a visual method to check for repetitive sequences. Granted, checking 65,535 graphed values would be quite the task. However, this is a good, quick way to look for any obvious, periodic repetition that may exist. The resulting graph should look like noise. In fact, the noisier the graph, the better the random number generator is.

Exploring some of the statistical functions in Excel allows for a more in-depth look at the RNG. For example, I ran the Histogram Data Analysis tool from `tools>>Data Analysis` in Excel to check the frequency of occurrence for each value in the test period that I graphed (refer to the Help files in Excel for more information). The resulting analysis is shown in Table 1. Note that each value is identified as part of a bin (statistical term for the value whose occurrence is being analyzed).

## Spicing Things Up

The application is basically



**PHOTO 3. Front view.**

complete at this point and it could be left as-is. However, what is life without a little spice?

Implemented in the firmware's `Check_button()` function, I include two `WHILE` loops. The first loop takes the current LFSR value when a pushbutton is pressed, modifies it by 6, assigns the new value to a variable `DIE_OUT`, and increments it by one for the duration of the loop, until the pushbutton is released. The `DIE_OUT` variable is eventually used to display the final value on the LED display for either dice. This adds user interaction as a variable to the final output value. Not only that, but a simple 50 ms delay is included in the loop and the output to the buzzer is toggled, so that each time through the loop, a  $1/50 \text{ ms} = 20 \text{ Hz}$  clicking sound is produced (mentioned previously).

The second loop occurs immediately after the pushbutton is released, and once again implements the buzzer output toggle. However, this time a variable called `Tumble` is

**TABLE 1. Results of histogram analysis of example random number generator.**

TABLE 1	
Bin	Frequency
0	1,568
1	1,555
2	1,526
3	1,566
4	1,560
5	1,598
More	0



initialized to 30 and then decremented by one each time through the loop. The Tumble variable is subtracted from the delay each time through so that the loop slows from 1/10 ms = 100 Hz down to 1/40 ms = 25 Hz, gradually slowing the buzzer's clicking sound before the firmware outputs a final dice-side value to the LED display.

In this way, we can imagine the first loop simulating the shaking

of the die while the pushbutton is pressed and the subsequent rolling of the die when the pushbutton is released. I also included some code to generate a sequential output of the values loaded in the DIE[6] array to the corresponding LED display in time with the rate of each loop.

Additionally, the PIC16F57 comes with a low-power SLEEP mode. Placing the device into SLEEP reduces

current consumption to approximately 1  $\mu$ A. Since there is no ON/OFF switch on the dice, the only way to remove power and preserve the two AAA batteries is to physically remove them. Therefore, to make for a more robust and efficient application, a counter variable Time\_2\_SLEEP is decremented with each overflow of the eight-bit Timer0. If Time\_2\_SLEEP reaches zero, the CCS compiler's specific function SLEEP() is executed and the device powers down. If at any time during this algorithm a pushbutton is pressed, the Time\_2\_SLEEP variable is reloaded and SLEEP is avoided.

Once in SLEEP mode, pushing the RESET button connected to the MCLR/Vpp pin will RESET the device, wake it from SLEEP, and start code execution over from the beginning. The time it takes before the microcontroller enters SLEEP is entirely base upon what value you initialize the Timer\_2\_SLEEP variable to.

## Final Thoughts

Even though a simple little circuit is used, the addition of an MCU enables the implementation of code with varying degrees of sophistication. Try playing with and testing the characteristic polynomial for the RNG using some of the techniques used in this article.

Typically, manufacturers of gaming equipment will run tests for days just to ensure the effectiveness of a random number generator. You could get fancy and delve into standard deviations and statistical analysis. Just explore the Data Analysis tools in the software you are using to generate your tests. Refer to the add-ins for Excel if these or other analytical tools are not present on your computer.

Remember, more than one characteristic polynomial will work for a register of a given size. Just be sure to follow the rules to develop a polynomial of maximal length. There are also other LFSR configurations out there you may wish to use. Roll the dice and let your imagination run wild! **NV**

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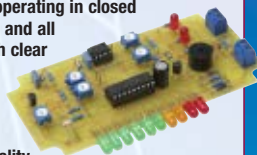


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# Jaycar Electronics



# PSYCHEDELIA II

## A Digital Color Organ

by Craig A. Lindley

In the September 1969 issue of *Popular Electronics Magazine*, Don Lancaster presented a color organ which he called Psychedelia I that I thought was the coolest thing I had ever seen. A color organ — as you may know — is a device that splits music up into numerous frequency bands and modulates colored lights (typically one color of light per band) according to musical content. In honor of Don Lancaster (my electronics hero) I named this color organ, Psychedelia II.

In Don's design, all of the functions of the color organ were done with analog circuitry, typical of the time. Don coupled transistorized active filters for frequency selectivity to triac, solid-state switching devices to control 110 VAC incandescent lights. All in all, a very nice design.

The problem I have with all analog color organ circuits I have ever seen or built is that as the musical material applied to the color organ changes, manual adjustments need to be made

to sensitivity controls on each channel to achieve a pleasant, balanced display. This constant adjustment gets old after a while, so fixing this problem was one of the motivations for designing a digital color organ.

The other motivation was to implement the design with a very small but powerful microcontroller (see Photo 1) using a development kit from Texas Instruments that cost just \$20. When I started down this path, I wasn't sure it was possible. I now know it was.

There is analog circuitry in my design, as well. In fact, the complete audio front end is analog. What is different about this design is that all of the frequency selectivity is provided by digital filters in the digital domain and the output devices are now low voltage super bright LEDs instead of incandescent bulbs. In addition, a digital automatic gain control (or AGC) was included to allow the color organ to adjust itself to varying musical material.

I described some of the technology used to implement this color organ in two previous articles for *Nuts & Volts Magazine*. See the articles entitled, "Floating Point Multiplication and Division without Hardware Support"

and "Lattice Wave Digital Filters" for additional background information.

## How It Works

This color organ has both hardware and software (firmware) components. Each will be described briefly here. For this discussion, the term microcontroller has been abbreviated as  $\mu$ C.

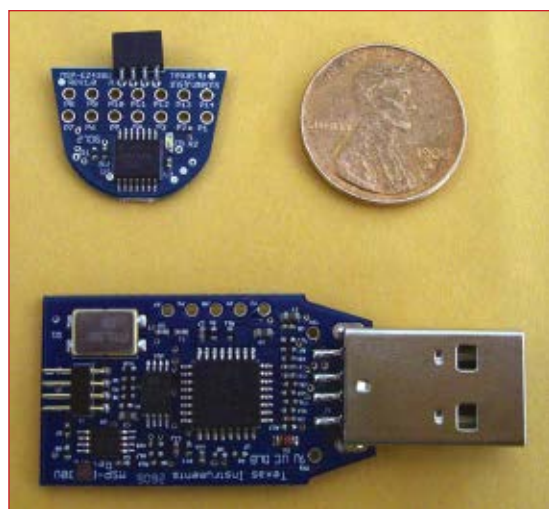
## The Hardware

As shown on the schematics, the hardware consists of three sections: the analog front end, the power supply section, and the output section. The analog front end is where the audio signals from either a built-in condenser microphone or a stereo line input are processed in preparation for analog-to-digital conversion inside the  $\mu$ C.

The built-in microphone has its own high gain pre-amp whose gain is controlled by trimmer pot R5. Stereo line level input signals are summed into a mono signal as this color organ is a mono device. Whichever audio source is selected for use, its bandwidth is limited to less than one half the sampling frequency of 16,000 samples/second as required by the Nyquist criteria.

Numerous first order low pass filters distributed throughout the circuitry, along with a second order Sallen-Key active filter, help limit the bandwidth to reduce aliasing effects when the audio signal is digitized. All of the analog circuitry runs single ended from a single five-volt power supply.

Power for the color organ is provided by a wall wart power supply which provides between 8 and 12



**PHOTO 1.** TI products used for the color organ. The MSP430F2012 target board in the upper left is the brains of the color organ. Its four pin connector plugs into the TI ez430 USB development system, lower middle, for programming and debugging.



VDC, depending on the load. Diode D1 prevents the DC power source from being connected backwards and causing damage. The raw DC is sent to the output section for powering the LEDs in the display. Two voltage regulators provide 5 VDC for the analog and TTL circuitry and 3.3 VDC for powering the MSP430F2012 target board.

On the output side, the 74HCT139 demultiplexes the pulse width modulation (PWM) signal from the  $\mu$ C used to control LED brightness. All four outputs are inverted in preparation for driving the output switching transistors. NOTE: 74HCT technology is required for reliably interfacing the 3.3 volt logic outputs of the  $\mu$ C with the five volt logic which follows.

Each color channel is driven by a switching power transistor. Resistors in each channel limit the current flow to around 200 mA to equalize maximum brilliance between channels. Resistor values in the output channels differ as a result of the differing forward voltage drops across the different colored LEDs. The output transistors run only slightly warm to the touch so heatsinks are not required.

There is hardware internal to the  $\mu$ C used by the color organ. Specifically:

- 1) A 10 bit analog-to-digital converter (ADC) is used to digitize the audio with a sampling rate of 16,000 samples/second.
- 2) Timer A is used to generate accurately timed PWM pulses to control the brightness of each output channel independently.
- 3) The watchdog timer functions as a general-purpose timer to generate periodic interrupts used to synchronize the display process.

As you can see, the  $\mu$ C provides a lot of useful hardware for this application.

## The Software

The complexity of this color organ is in the real-time nature of the software. There are three distinct threads of execution at work: the main thread, the sample acquisition and processing

thread, and the display thread. (Consult the program listing for the details.)

## The Main Thread

The main thread starts every time the  $\mu$ C powers up and performs all hardware and application initialization including:

- 1) Setting up the port bits needed to drive the output demultiplexer.
- 2) Setting up the ADC for operation and configuring a pin on the  $\mu$ C for analog input.
- 3) Setting up the watch dog timer for generating periodic interrupts.
- 4) Setting up Timer A for PWM operation.
- 5) Initializing application variables.
- 6) Enabling interrupts.
- 7) Putting the ADC into the automatic single channel sample acquisition mode.

With initialization complete, the main thread enters an infinite loop doing nothing forever.

## The Sample Acquisition and Processing Thread

This is where time-critical activities occur. You can visualize this code as having one input (the new sample) and four outputs (the output of the four color organ channels). This code runs 16,000 times per second. Each new sample is subjected to the following processes:

- *Noise Gate* — The noise gate monitors each newly digitized sample

to make sure it is above a minimum value before being allowed to pass. Values smaller than the minimum are replaced with a zero valued sample.

- *Decay Processor* — The decay processor monitors the sample stream for long runs of zero valued samples. Two things happen when a lull in the audio is detected. First, all of the filter delay elements are reset to terminate any ringing of the filters and second, the AGC gain variable is set to unity (Gain = 0) causing the AGC processor to restart its gain control function. The decay processor guarantees the display goes dark between songs and in low volume passages.

- *The AGC Processor* — The AGC processor is made up of two parts: the AGC gain control element and the AGC state machine (SM). The SM can be considered the brains of the AGC processor; the gain control element, the brawn.

A Gain value of zero indicates unity gain and the samples flowing through the gain element are untouched. Each incremental value of Gain causes a sample to be left shifted. If Gain is 4, samples are left shifted four times for a gain of 16. The AGC manipulates sample amplitude by applying more or less gain to the samples as they flow through the AGC Gain element.

There have been many AGC designs over the years, but I may have invented a new variety by using a state machine to control gain. To understand the operation of the SM in detail, you should consult the code listing. Basically, the SM runs every sample period and has a total of four states. The SM runs to completion every 1/16th of a second or every 1,000 samples.

The result of the SM execution is

Color Organ Band	Filter Type	Frequency	Filter Method	Response Graph
Low	Low pass	115 Hz	Chebyshev	Figure 1
Low-Mid	Band pass	600 Hz	Cauer/Elliptic	Figure 2
Mid-High	Band pass	2.4 kHz	Cauer/Elliptic	Figure 3
High	High pass	6.2 kHz	Chebyshev	Figure 4
All filters were designed using LWDFDesigner.java, discussed in a previous article.				
TABLE 1				

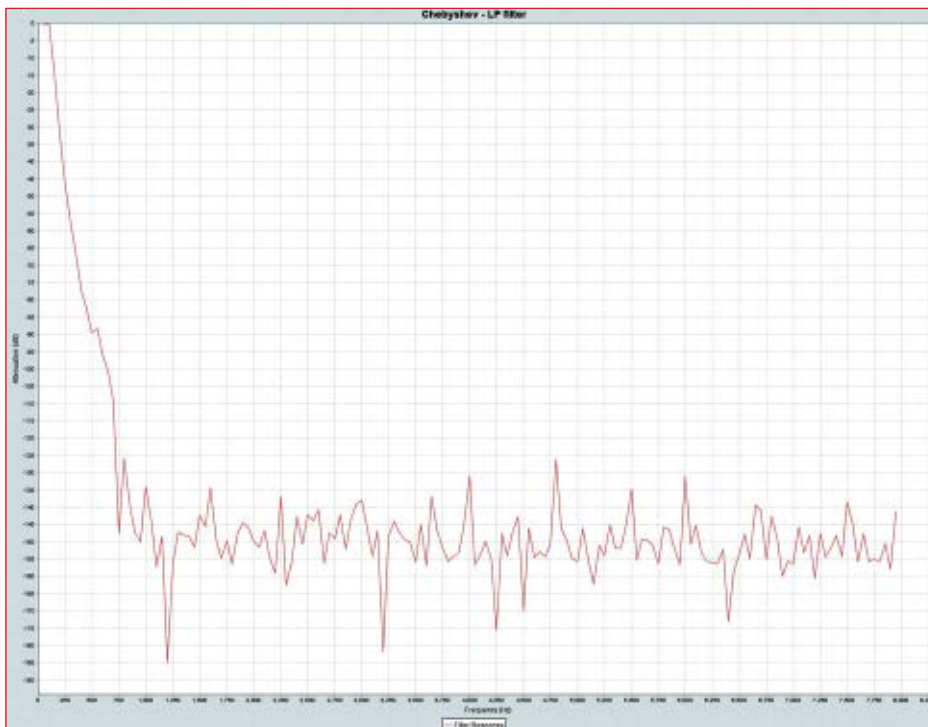


FIGURE 1. Low band filter.

hardware in the  $\mu$ C. The following operations are required:

- 1) Sample value replaced by its absolute value.
- 2) Sample is compared to a min threshold and, if smaller, is replaced by a value that causes the channel to remain off during its display period.
- 3) Sample value is clipped to a maximum value, if required.
- 4) Sample value converted into a range necessary for the PWM hardware.
- 5) Processed sample is stored in memory for the display process thread.

## The Display Thread

The display processor is executed every 256 microseconds by the watchdog interrupt. One channel of color organ output is done each interrupt. The display processor (see `wdt_isr` in the listing) performs the following operations:

- 1) Disables Timer A's PWM output line.
- 2) Determines which channel of output to display from the value of Slot.
- 3) Sets the output port bits to select the appropriate output channel from the demultiplexer.
- 4) Fetches the processed PWM value for the selected channel and loads it into Timer A's compare register.
- 5) Resets Timer A's counter and starts the PWM output.
- 6) Increments Slot and returns from the interrupt.

Four new values of processed PWM data are stored in memory every 62.5 microseconds but the display processor only picks up one of these values every 256 microseconds for display.

FIGURE 2. Low mid band filter.

the manipulation of the Gain variable used to control the AGC Gain element. The value of the Gain variable can change by at most, one; each execution of the SM which allows the gain to change up to 16 times a second as different program material is applied to the color organ.

• *Digital Filters* – The four channels of

the color organ represent four bands of frequency selectivity implemented using third order lattice wave digital filters. Each acquired sample is processed by all four filters. Table 1 gives the specifics.

• *PWM Processing* – The final step in the real-time processing of samples is the conversion of the filter outputs into a form that can drive the PWM





FIGURE 3. High mid band filter.

## Real Time and $\mu$ C Resource Analysis

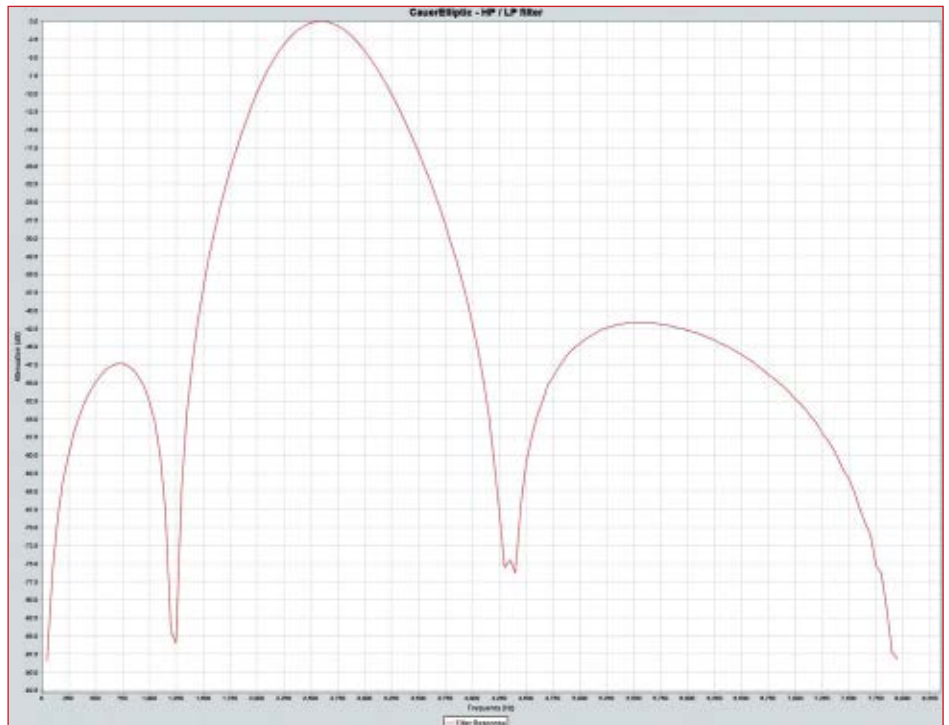
During the design of the software, I had to determine if the MSP430F2012  $\mu$ C had the performance necessary to handle the color organ's real-time requirements. Specifically, with the  $\mu$ C clock running at 16 MHz and a sample rate of 16,000 samples/second, there was a maximum of 1,000 instruction cycles available per sample period. Luckily, many of the instructions (all register to register instructions) execute in a single cycle. When I did my initial calculations, I found the processor was over-committed by some 20%, meaning the processing of the audio samples were taking longer than real time allowed. Needless to say, this is bad.

The easiest fix for this real-time overage would have been to eliminate one of the color organ's channels, but I was reluctant to do that. Instead, I decided to optimize the real-time software so it could execute completely in the allotted time. Optimizations included:

- 1) Moving 95% of the code in-line to eliminate almost all subroutine calls and returns.
- 2) Moving all of the real-time code directly into the interrupt service routines.
- 3) In-lining code for small subroutines that were used in multiple places in the code. In other words, I used additional code space to boost performance.

With these changes, I estimate the color organ is now using roughly 95% of the available CPU cycles. If you plan on making changes to the software, please keep this fact in mind.

In terms of the hardware internal to the  $\mu$ C, it is all being used except for a few port lines. There are about 240 unused bytes of code (Flash) memory remaining and, assuming a maximum of five levels of subroutine nesting (the stack uses RAM), there are about 57 remaining bytes of RAM. I think it is safe to say this color organ application



uses up the MSP430F2012  $\mu$ C almost completely.

## Building One

This color organ can be built for approximately \$100. MSP430F2012 target boards are available from TI (three for \$10), but you will have to program them with the code provided.

I made a 12" cable that plugs between the USB development hardware and the target board so I could program the  $\mu$ C in place after the color organ was built. You could, of course, program the  $\mu$ C first and then attach it to the color organ. Note two things:

- 1) Resistor R1 on the target board should be removed to prevent a power

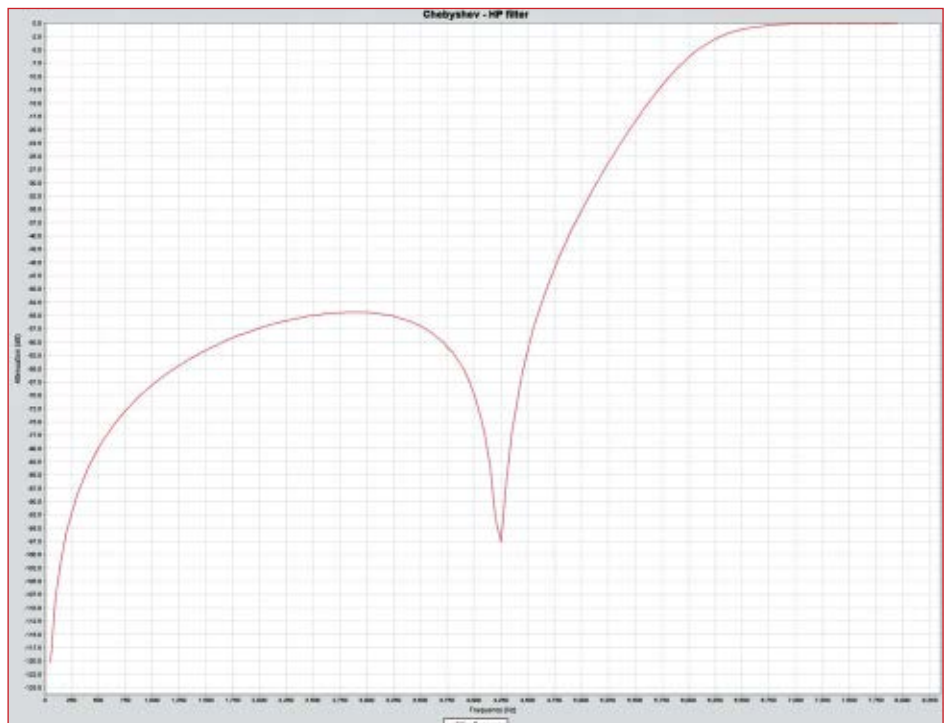
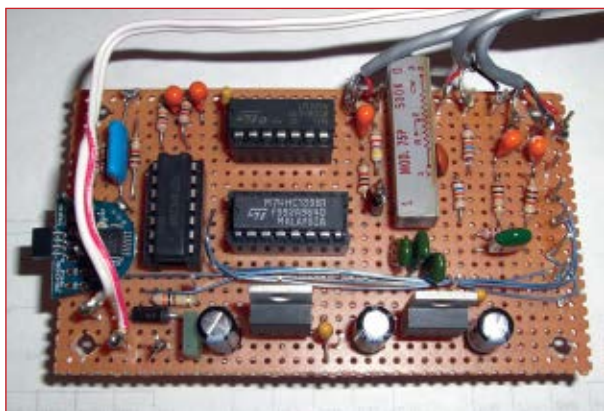


FIGURE 4. High band filter.



**PHOTO 2.** Color organ controller board. The  $\mu$ C target board is on the left side of the board. Power supplies are built across the bottom.

perf board in the proper positions so that the target board could be slid on and soldered. The wire wrap pins not only provide the electrical connections but also provide the physical support for the target board.

supply conflict between the color organ and the USB development hardware. Removing this resistor means the target board will always be powered by the color organ's power supply.

2) There is an LED on the target board which will be on while the color organ is operational. The LED can be removed if this is a problem.

Build the color organ using the schematics and parts list as your guides. I used wire wrap, but you can build it anyway you choose. I built the main controller portion of the color organ on one perf board and the output section on another, but they could have been built on a single board.

Six connections are required between the target board and the color organ. Since the I/O pin holes on the target board are on .1" centers (the same as the perf board I was using), I pushed wire wrap pins through the

I packaged the color organ in a triangular box I purchased. The box seemed about the right size for the 40 LEDs I was going to use for the display. I replaced the glass front that came on the box with diffusion plastic from the hardware store. The plastic I used causes the LEDs to appear like fuzzy circles of color about 1-1/4 inch in diameter. The back panel of the box has convenient swivel tabs that lock into slots on the box which make taking the color organ apart and putting it back together very easy.

The LED leads were bent around toward the LED and glued directly to the box's rear panel. I laid out the LEDs in geometric patterns, but you can lay them out anyway you want. Wire-wrap wire was used to connect the LEDs together and to the output board.

The color organ's control panel was built from a piece of sheet metal. The control panel has the line input jax, a condenser microphone, the mic/line switch, and the power switch.

I decided to hard-wire the power supply to the unit, so I drilled a hole in the back panel and ran the power supply wire through it. I then tied a knot in the wire inside the box for strain relief.

Once your color organ is assembled, do the following:

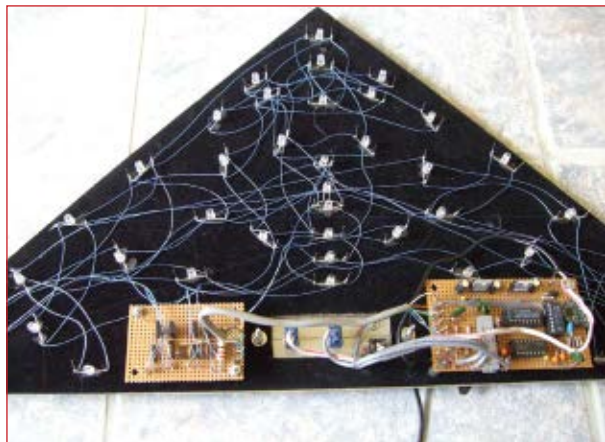
1) Plug in the wall wart and turn on the power switch to check the power supplies. You should have 3.3 VDC, 5 VDC, and a high voltage output between 8 and 12 VDC. If there is a problem with a power supply, find and fix it before continuing. Check for power and ground at each socket before installing the ICs.

2) Program the  $\mu$ C with the provided software.

3) With the  $\mu$ C programmed, you should see the LED on the target board light up (assuming you haven't removed it yet). It should come on with the power and stay on indicating the display processor is running.

4) Perform an initial calibration of the microphone preamp's gain. This can be done by connecting a headphone through a capacitor (10  $\mu$ F will do) to the preamp output and adjusting the trimmer for no distortion. After your color organ is working correctly, you may need to back down the preamp's gain so the color organ's display is not completely saturated when the mic source is selected.

**PHOTO 3.** The color organ is built onto the rear panel of the display box. The wire out of the bottom is connected to the wall wart power supply. The output board is on the left, the control panel is in the middle, and the controller board is on the right.



**PHOTO 4.** Rear view of the color organ. Black spot on the top left of the control panel is the condenser microphone. Below it is the line input jax. Next is the mic/line switch and furthest to the right is the power off/on switch. You can see the swivel tabs that lock the back panel into place.





PHOTO 5. Front view of the color organ.

5) Connect a line input source and connect your headphone/capacitor between the arm of the mic/line switch and ground. You should hear the output of the microphone in the mic position and hear the line input source in the line position.

Once these checks are successful, you should have a working color organ.

## Conclusions

I would say this color organ project was successful. The color organ performs the function it was designed to do and illustrates what can be done using DSP techniques on a very small  $\mu\text{C}$ . Is the software perfect? Probably not, but it works. Does the color organ look cool in operation? Yes, it does.

The experience using the TI development tools was a very pleasant one.



The \$20 development kit and the provided software worked without a hitch and proves that TI has indeed brought  $\mu\text{C}$  development to the masses.

I do hope some of you build the color organ. It may not be the '60s any longer, but it is still fun to watch lights flashing to your favorite music. **NV**

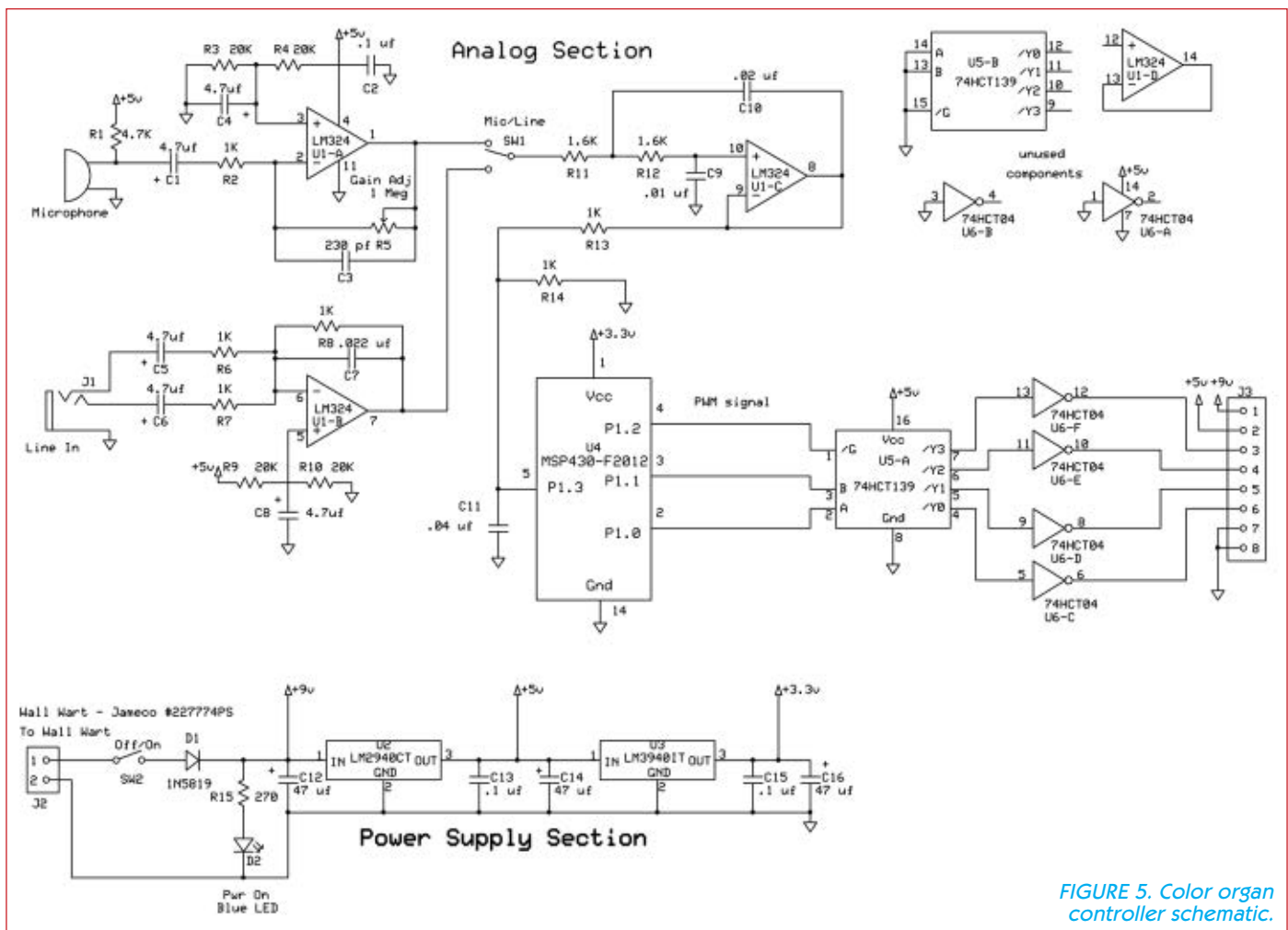


FIGURE 5. Color organ controller schematic.

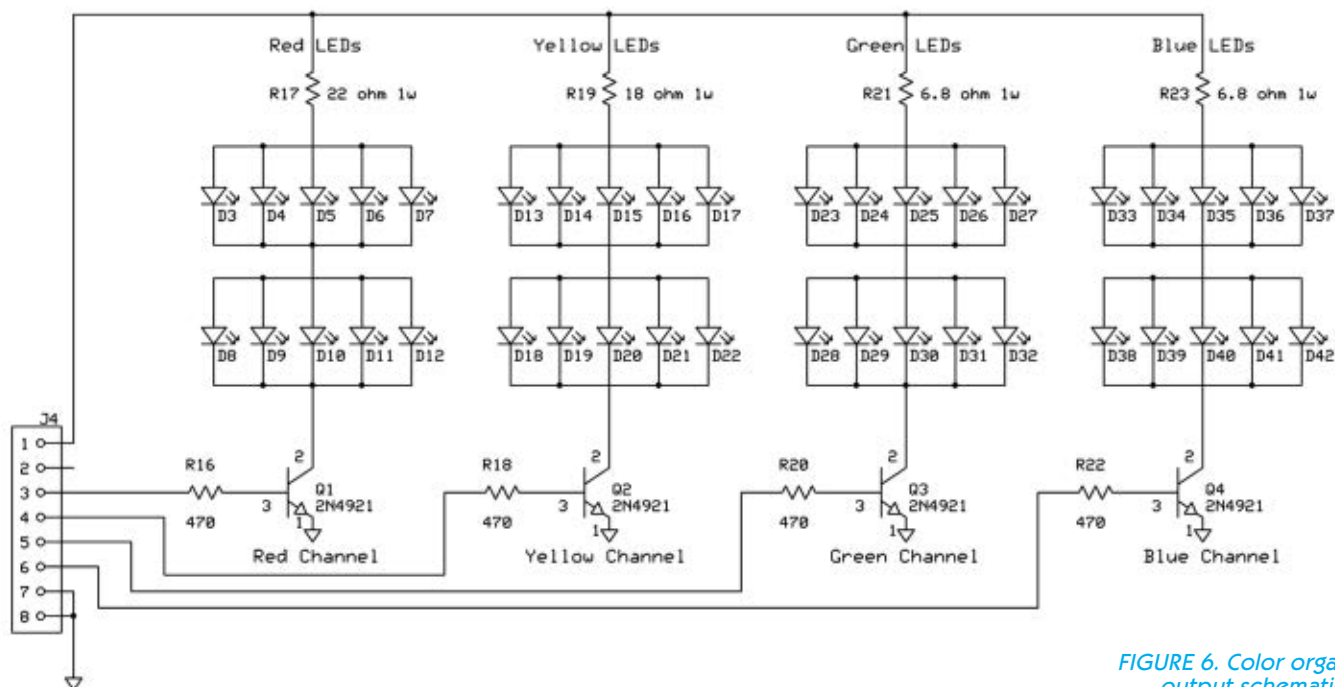


FIGURE 6. Color organ output schematic.

## COLOR ORGAN PARTS LIST

ITEM	DESCRIPTION	NOTES
• C1,C4,C5,C6,C8	4.7 $\mu$ F capacitor	
• C2,C13,C15	0.1 $\mu$ F capacitor	
• C3	230 pF capacitor	
• C7	0.022 $\mu$ F capacitor	
• C9	0.01 $\mu$ F capacitor	
• C10	0.02 $\mu$ F capacitor	
• C11	0.04 $\mu$ F capacitor	
• C12,C14,C16	47 $\mu$ F capacitor	
• R1	4.7K resistor	Polarized
• R2,R6-R8,R13,R14	1K resistor	1/4W 5%
• R3,R4,R9,R10	20K resistor	1/4W 5%
• R5	1 meg trimmer	10 or 20 turns
• R11,R12	1.6K resistor	1/4W 5%
• R15	270 ohm resistor	1/4W 5%
• R16,R18,R20,R22	470 ohm resistor	1/4W 5%
• R17	22 ohm resistor	1W
• R19	18 ohm resistor	1W
• R21,R23	6.8 ohm resistor	1W
• D1	1N5819 diode	Optional reverse voltage protection diode
• D2,D33-D42	Blue LEDs	RL5-B4630
• D3-D12	Red LEDs	RL5-R5015
• D13-D22	Yellow LEDs	RL5-Y5030
• D23-D32	Green LEDs	RL5-G5023
• J1	Stereo 3.5 mm/1/8" jax	Line input connector
• J2	Two wire power jax	Optional
• J3/J4	Inter-board connections	Optional
• M1	Condenser microphone	Jameco #160979
• Q1-Q4	2N4921 switching/power transistor	Heatsinks aren't necessary
• SW1	SPDT	Mic/line switch
• SW2	SPST	Power off/on switch
• U2	LM2940CT	Five volt, one amp voltage regulator
• U3	LM3940IT	3.3 volt, one amp voltage regulator
• U4	MSP430-F2012	uC target board. Available from TI. (See Resource sidebar.)
• U1	LM324	Quad op-amp
• U5	74HCT139	Two to four demultiplexer
• U6	74HCT04	Hex inverter/buffer

## CONTACT THE AUTHOR

Craig A. Lindley can be contacted via email at [calhjh@gmail.com](mailto:calhjh@gmail.com)

## RESOURCES

The color organ source code file — colororgan.s43 — is available from the *Nuts & Volts* website at [www.nutsvolts.com](http://www.nutsvolts.com).

Information on the Texas Instruments eZ430 development kit is available at <http://focus.ti.com/docs/toolsw/folders/print/ez430-f2013.html>.

The LEDs used in this project were purchased from [www.superbrightleds.com](http://www.superbrightleds.com).

Other parts for this project were purchased at Jameco and RadioShack.





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# Basic Analog Power Supply Design

by Gerard Fonte

## Part 2

**In the first part, we saw that there are three main components to an analog power supply: input power conversion and conditioning, rectification and filtering, and regulation. We examined the first two components and in this article we will examine the regulation aspect. We will concentrate on the basic three-terminal regulators that are cheap and easy to obtain.**

However, it should be remembered that many of the basic design aspects of three-terminal regulators apply to any analog regulator design. In this article, a zero to 30 VDC, zero to one amp, current limited power supply will be developed. The basic cost for parts is under \$25.

### Basic Three-Terminal Regulator

Figure 1 shows a conceptual design of a three-terminal regulator. (We will limit our discussion to positive regulators because the negative regulators are virtually the same, other than polarity.) It is important to appreciate how this works in order to properly understand and apply analog regulator concepts. Fundamentally, the regulator is a negative-feedback servo system. The resistor and zener diode provide a stable voltage reference to the

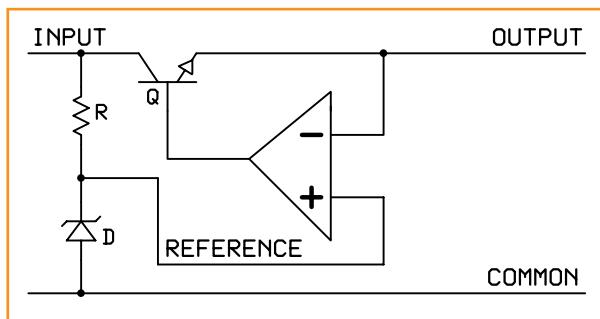
non-inverting input of an op-amp. The inverting input of the op-amp measures the output. If the output is higher than the reference, the op-amp slews towards a lower voltage.

Conversely, if the output is lower than the reference, the inversion of the op-amp's input drives the base of the transistor harder to allow a higher voltage to pass. This design concept is pretty straightforward (although implementing it can be fairly complex).

There are a number of points about this basic design that need discussion. The first is that the pass transistor is acting as a variable resistor. It reduces the input voltage by limiting the current. As you can imagine, a fixed resistor in this situation must be able to dissipate plenty of heat, so it's the same for the transistor. We will examine this in more detail later.

The second point is that there is a voltage drop across the pass transistor.

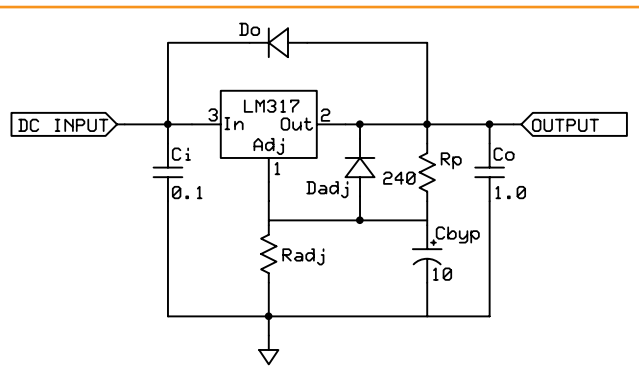
All bipolar semiconductor junctions display this effect. This means that the input voltage must



**FIGURE 1.** The basic approach to the three-terminal regulator is a simple negative feedback op-amp circuit. Although in practice, it's a bit more complicated than this.



**FIGURE 2.** The practical implementation of the LM317 adjustable regulator requires a few additional components for optimal performance and reliability. The text describes the additional parts and their function.



be higher than the output voltage for proper operation. For the standard three-terminal voltage regulators, this voltage is about 1-2.5 V, depending on temperature and current drawn. (However, for proper design purposes the 2.5V “drop-out” voltage should always be employed.)

If the desired input-output voltage difference is less than this 2.5 V, the circuit will no longer have the headroom to regulate properly and drop out of regulation. (There are other “low-dropout” or LDO regulators available that can operate with much less input-output differential – some as low as 0.1 V. However, care must be taken to provide proper capacitive loading or else they may not function properly.)

The third point is that it takes some small amount of time for an output change to propagate through the op-amp and transistor (loop delay). During this time, the output is not being properly regulated. Obviously, the faster the op-amp and transistor, the shorter this transient will be. However, manufacturing fast, high-power transistors is not easy or cheap.

Additionally, the faster the transistor and op-amp circuit is, the more prone to oscillation it is. Having your power supply oscillate is not a good thing. Most three-terminal regulators have a transient response (closed-loop delay time) of about 30 μs.

The last point concerns adjustable voltage regulators (Figure 1 shows a fixed-voltage regulator). Without getting into a long technical discussion, it is difficult to provide a stable and cheap reference voltage below 1.2 V. This limits the minimum output

voltage of adjustable regulators. However, we’ll see a cheap and easy solution to this problem, later.

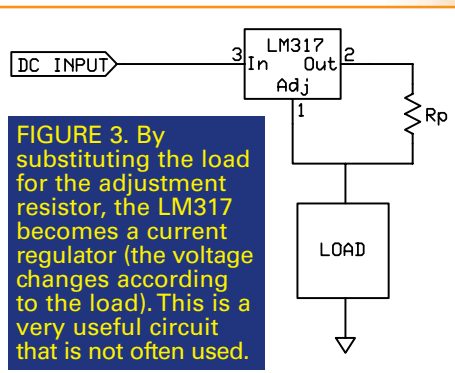
## Additional Components Needed

For the fixed voltage regulator, only an input and output bypass capacitor (connected to ground) are required (typically 0.1 to 1.0 μF). These are to stabilize the op-amp in the regulator. If the large filter capacitor is in close physical proximity (less than 6”) to the regulator input, then the input bypass capacitor can be omitted.

In theory, the output capacitor can also be omitted. But if your circuit to be powered just happens to have a load capacitance of 500 pF to 5,000 pF, then the regulator might oscillate. Using a 1.0 μF output bypass capacitor forces the op-amp into a stable operating mode. It is always a good idea to spend a few pennies on this to be sure you have a reliable power supply.

Figure 2 shows the proper design for an adjustable regulator. The input and output bypass capacitors (Ci and Co) are the same as in the fixed regulator implementation.

The two resistors (Rp and Radj) are required to choose the output voltage. Typically, Rp is set at 240 ohms to provide a proper current (typically about 50 μA) into the feedback of the op-amp. Radj is used to vary the output to the desired value. The capacitor connected to the adjustment pin (Cbyp) is used to improve ripple/noise rejection. This is especially useful if the raw DC input is coming from a



**FIGURE 3.** By substituting the load for the adjustment resistor, the LM317 becomes a current regulator (the voltage changes according to the load). This is a very useful circuit that is not often used.

switching power supply which is typically quite noisy.

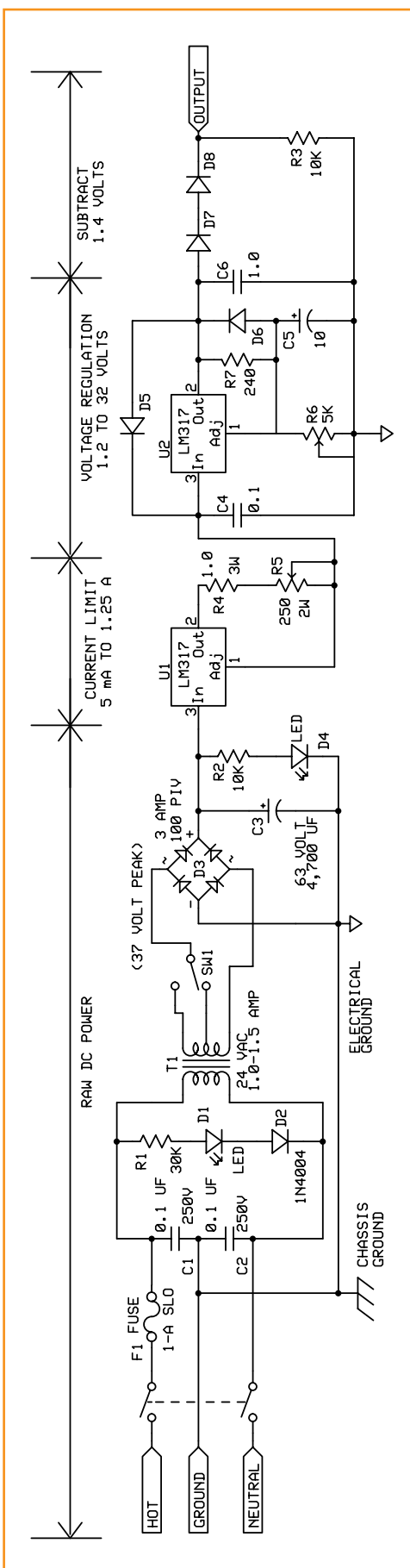
The diodes are used to protect the regulator against unexpected voltage reversals. If the input should be shorted to ground, capacitors on the output and/or the adjustment pin will still maintain their voltage. They will then discharge backwards through the respective pins towards the input. This can destroy the device.

If there is no adjustment bypass capacitor used (Cbyp), then the Dadj can be omitted. If you are sure that the device being powered will never have 10 μF or more load capacitance, then Do can be omitted, as well.

## Adjustment Calculations

It is important to remember that (for adjustable regulators) the adjustment pin acts as a non-inverting feedback point to the internal op-amp. As such, the op-amp will do whatever it can to maintain the voltage on this pin (which is specified to be 1.25 volts below the output). So if we apply a voltage (through a resistor) to this pin, the output will go up. If we short this pin to ground, then the output will fall to about 1.25 volts. If a negative 1.25 volts is applied, then the output will go all the way to zero volts.

Generally, a voltage divider is used to pass some of the output voltage back into the regulator to set the output voltage (as shown in Figure 2). The equation is  $V_{out} = V_{ref} (1 + R_p/R_{adj}) + (I_{adj} \times R_{adj})$ . Vref is 1.25 V as noted above. The second term ( $I_{adj} \times R_{adj}$ ) is the error correction for the 1.25 V reference. Generally this is quite small and is often ignored. If this is ignored and the typical value of 240



**FIGURE 4.** This is a nice bench power supply that provides 0-30 volts at one amp. It's also current limited to help eliminate unnecessary smoke generation in your circuits. Meters to monitor the voltage and current can be added, if desired.

$\Omega$  is used for  $R_p$ , then the equation becomes  $V_{out} = 1.25 (1 + 240/R_{adj})$ . Usually, this is accurate to within a few percent.

A curious thing happens when we replace  $R_{adj}$  with a power load instead of a resistor (see Figure 3). The output voltage varies with the load. We see that this makes sense because the power load variation is acting as a variable resistor. The result is that the current to the load remains fixed but the voltage varies. In other words, the voltage regulator has changed into a current regulator. Instead of a constant voltage, we have a constant current.

It is easily seen that the maximum current allowed depends upon  $R_p$ . If  $R_p$  is made  $1.25 \Omega$ , then up to a full amp of current can be supplied. Note that this current is limited by the 1.5 A maximum output of the regulator and the maximum output voltage obtainable (which depends upon the input voltage). This current regulation is a very useful feature (of these regulators) that is not often used.

## Power Dissipation

Basically, the regulator acts like a variable resistor in series with the power supply. The amount of power dissipated is simply the voltage difference between the input and output pins times the current drawn. This creates some interesting situations.

For example, suppose you provide 35 V to the input of an adjustable regulator and expect to draw one amp at five volts and also at 32 V. At five volts, there will be a 30 V drop across the regulator. With an amp of current, the regulator will have to dissipate 30 W while providing five watts to the load. It's only 14% efficient. At

32 volts, there will be a three volt drop which means that the regulator must dissipate just three watts while supplying 32 W to the load. This is 91% efficient.

It is clear that keeping the input voltage as close to the output as possible results in better efficiency and less heat. (Note that with an input voltage of 35 V and a current requirement of one amp the total power used will always be 35 W. The more power the load uses, the less the regulator must dissipate.)

Often times, multiple voltages are needed for a circuit. There is nothing wrong with placing a five volt regulator after a 10 V one. In this way, the voltage drop for the five volt regulator is shared between two devices. However, if the two voltages have significantly different current requirements, this approach may not be optimal. (You can use Ohm's Law to calculate the effective resistance of the regulator given the desired voltage and current. The power is then calculated to be the resistance times the current squared.)

## Applying the Theory

We can now combine the information from the two articles to build a practical power supply. We'll start with a basic supply and then discuss how to change it to add features that may be useful. Figure 4 provides a practical circuit for an adjustable, current limited and voltage regulated, one amp power supply that goes from zero volts to about 30 volts. (This particular circuit has proven to be very useful and adaptable in a number of high-reliability designs for my clients, usually with fixed current limit and fixed output voltage.)

The raw DC circuit was described in detail last month and will not be discussed further except to note a few minor changes. The power transformer is now specified as a 24 volt, center-tapped, 1.0 to 1.5 amp device instead of 25.2 volts at two amps. The reason for this change is three-fold.

The first is that some regulators are limited to 35 V (most others are rated to 40 V and there is a high



voltage version — LM-317H — that can go to 60 V). Note that this is technically the voltage differential between input and output, not from input to ground. If the output is maintained above ground, then the input can be higher.

However, for a general-purpose power supply you must assume the output will be shorted to ground from time to time. This means that the input voltage must be limited to about 37 V because there will be about 1.4 V dropped by the bridge diode and an additional 2.5 V dropped by the current regulator.

Also, there is no reason to provide two amps of primary DC current if the maximum output is rated at one amp. (Note that the rating is less than the absolute maximum the circuit can provide.) The third reason is for regulator heat control. This is also the reason for the added switch which will be discussed in more detail below.

The main filter capacitor has been reduced from 10,000  $\mu\text{F}$  to 4,700  $\mu\text{F}$  because the power supply current specification has been reduced from two amps to one amp.

The adjustable current regulator is just three parts: an LM-317, a fixed resistor, and a variable resistor. The fixed resistor is necessary to limit the current through the resistor string. Obviously, as the resistance gets lower, more current flows. With a 1.25 V differential between the output and adjustment pin, the one ohm fixed resistor limits the current to 1.25 A.

If this resistor was eliminated and the adjustable resistor was set to 0.1  $\Omega$  for example, the current would be (theoretically) 12.5 A (using Ohm's Law). This would either destroy the IC or cause it to shut down from thermal overload. Neither is good.

Also, the power through that small resistance would be 15.6 W (power is equal to current squared times resistance). This would burn the variable resistor. By forcing a minimum of 1.0  $\Omega$  in the circuit, the current is limited to a maximum 1.25 A and the variable resistor is protected.

The worst case power dissipated by the fixed resistor is 1.25 W. A

three watt resistor (rather than a two watt device) is chosen to be conservative. The worst case power requirement of the variable resistor occurs when it is equal to the fixed resistor or 1.0  $\Omega$ .

In this instance, there will be about 0.4 W of power through it. This means that a one watt potentiometer is adequate, but a two watt unit will be used to be very conservative. Remember, it's better to spend a little bit extra on the power supply than to spend a lot on ruined circuits.

The voltage regulator section is simply the design from the beginning of this article. The only change is to use a variable resistor (R6) instead of a fixed resistor (Radj).

Heatsinking is an important issue. The voltage regulator must be able to dissipate up to 32 W of power, worst case. This creates a significant problem. The typical TO-220 case is limited to 15 W as per the spec sheet. One poor solution is to reduce the maximum power rating to about 0.5 A for lower voltages. This is changing the specs to match the design instead of designing to match the specs. There is another approach that requires a bit of creative engineering that will be detailed below.

Curiously, the current regulator is very efficient. The voltage drop is typically 2.5 V (worst case) so the maximum power dissipated at one amp is 2.5 W. A simple and inexpensive clip-on heatsink is sufficient here.

## Fixing the Heat Problem

As noted, there is too much heat to be dissipated at low voltages. The problem comes from the large voltage drop from the input to the output of the regulator. The solution is to use a center-tapped transformer and switch between taps. Center-tapped transformers are common and generally cost no more than non center-tapped transformers.

When the switch is connected to the top end of the transformer, the full voltage is applied to the rest of the circuit and the full range of voltages is possible. As long as the current draw is kept below about 0.5 A, there will

be no heat problem. However, if the power supply needs to provide a high current at a low voltage, the switch is used to connect to the center-tap and reduces the input voltage by 50%. Thus, only about 18 volts is applied to the rest of the power supply.

So, if five volts at one amp is needed, then only 13 W of power must be dissipated by the regulator as heat (instead of about 30 W). This allows the standard TO-220 style regulator to be used within the specified limits. (If you want to get fancy, you could monitor the adjustment voltage and use a separate circuit to automatically switch between the transformer windings.)

## Fixing the Minimum 1.2 Volt Problem

Most people want a power supply to go all the way to ground. It turns out that there is an easy way to accomplish this: just add two diodes in series with the output. Each diode drops the voltage by about 0.7 V (depending on load). So, two diodes will reduce the output by 1.4 V. In actual operation, only about 1.0 V is dropped at no load. This makes the minimum output no load voltage 0.2 V. This is virtually zero.

If you really want to, you can add another diode in series to drop the output further, but it seems unnecessary. The resistor to ground is included to drain off any leakage through the diodes. Without the resistor, the output can float up to the voltage applied to the diodes.

It should be noted that you can pull the output of the regulator to ground if you apply a negative voltage to the adjustment pin. This is somewhat complicated if a negative voltage is not easily available (as in this case). The addition of two diodes is a quick and easy fix.

## Minimum Current Discussion

As noted on the schematic shown in Figure 4, the minimum current limit is about 5 mA. For virtually all applications, this is not a problem. Very few components will

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be damaged with 5 mA applied to them. However, if the voltage is set to 30 V, then 150 mW of power is present at the output. This could be too much for some components. It must be remembered that the voltage regulator uses some current for its operation (in addition to the current dissipated during the process of regulation). As it happens, the regulator draws about a constant 5 mA with a 30 V input, regardless of the voltage output setting. Therefore, while the current regulator provides a minimum of 5 mA, this current is used by the following voltage regulator and it is not seen at the output to a great degree (although in certain special cases it might be). This is not a perfect solution, but it is reasonable.

If desired, a larger current adjustment resistor (R5) can be used. A 1K potentiometer will reduce the minimum current out of the current regulator to about 1 mA.

## Adding Meters

It's always nice to be able to measure the voltage output and current used. Adding a voltmeter is simple. Just place it across the output to measure the voltage.

The current meter is a bit more complicated. You can place an ammeter in series with the output to measure the current used. This will work most of the time. The problem is with the series resistance added by the meter. Depending on the meter, this might affect the circuit you are powering. Basically, it increases the power supply impedance. This is especially true for low current ranges where the series resistance may be a hundred ohms or more (my cheap

meter has 800  $\Omega$  of resistance on the 500  $\mu$ A scale).

If you don't mind an error of a few mA, there is a very convenient place to measure the current. All you have to do is measure the voltage across the leads of R4 in the current limiting circuit. This is a one ohm resistor and will provide one volt per amp of output current.

The basic accuracy depends upon the precision of the resistor. A 1% resistor will be accurate to 1% except for the few mA used by the voltage regulator circuit that follows. (Note that you can measure small load currents by noting the current before connecting the load and after it has been connected. The difference is due to the load. Your basic limitation here is the ability to measure small voltages. Five mA of current will provide only 5 mV across the resistor.)

The proper method of measuring the output current is to add a small series resistor to the output and measure the voltage drop across it (just like we did with R4). Typically, this resistor is 0.1  $\Omega$  or less and requires a bit of careful design. There are current monitor ICs available for a couple of dollars that greatly simplify the problem of converting a current into an easy to measure voltage.

## Conclusion

Understanding basic analog power supply concepts allows the design of a robust, general-purpose power supply for under \$25. Adjustable three-terminal regulators are inexpensive and their shortcomings can be compensated for without too much trouble. Higher current and higher voltage regulators are available so that larger power supplies can be built.

Instead of providing only a circuit diagram and instructions, these two articles have attempted to provide a foundation of information needed to help anyone design a power supply for their own needs. Power supply design is a basic skill every engineer and hobbyist should have. After all, every project needs to be powered in some way. **NV**

## Power Supply Parts List

ITEM	DESCRIPTION
R1	30K 1W
R2, R3	10K
R4	1.0 $\Omega$ 3W
R5	250 $\Omega$ 2EW adjustable
R6	5K

Resistors 1/4 watt 5% unless otherwise specified



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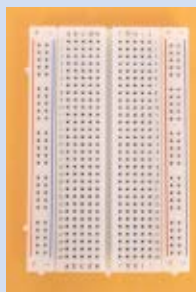


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# GETTING STARTED WITH PICs

THE LATEST IN PROGRAMMING MICROCONTROLLERS



■ BY CHUCK HELLEBUYCK

## PICKIT™ 2 COMMAND-LINE OPTION

**I HAVE GOOD NEWS FOR ALL THE USERS of Microchip Technology's PICkit 2 programmer who want to use it with an Integrated Development Environment (IDE) other than Microchip's MPLAB® IDE. Microchip has released a DOS command-line option for the PICkit 2, and I've successfully used it with the MicroCode Studio IDE from Mecanique ([www.mecanique.co.uk](http://www.mecanique.co.uk)) and microEngineering Labs' PICBASIC PRO™ sample version ([www.microengineeringlabs.com](http://www.microengineeringlabs.com)).**

**T**his is the ultimate starter setup, as most of these software tools are free. You can download the PICkit 2 command-line software from [www.microchip.com/pickit2](http://www.microchip.com/pickit2). The download is a zip file, so you need to download it and then unzip it into a location on your hard drive. The final step is to connect the PICkit 2 to the USB port on your PC, and then set up the PICkit 2 in the MicroCode Studio IDE for that one-click compile/program feature most of us want.

Studio. Figure 3 shows the "Add New Programmer" window that appears. The "Create a custom programmer entry" should already be selected, so click on the "Next >" button.

A second "Add New Programmer" window will appear with a blank line. Enter the name you want to appear in the programmer selection window when you select your programmer at

compile time. I chose to call it simply "PICkit2," as you can see in Figure 4.

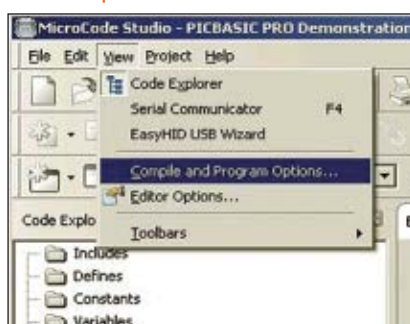
After you enter the programmer name, click the "Next >" button and the "Editing PICkit2" window will ask for the PICkit 2 command-line executable. If you chose a different name, the window title will show the name you selected. The command line executable for the PICkit 2 is the

### PICKIT 2 SETUP

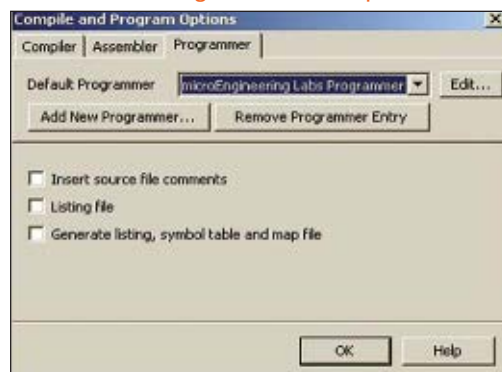
The steps to set up the PICkit 2 in MicroCode Studio are easy, once you know what to do. First, open MicroCode Studio, and then click on the "View > Compile and Program Options" selection as shown in Figure 1. The window shown in Figure 2 should appear.

The next step is to click on the "Add New Programmer" button to create the PICkit 2 setup in MicroCode

■ FIGURE 1. Programmer Set-up Menu Option.



■ FIGURE 2. Programmer Set-up Window.



■ FIGURE 3. Add New Programmer Screen.



■ FIGURE 4. Enter PICkit 2 in Window.



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■ FIGURE 5. Enter PICKit 2 Command Line.

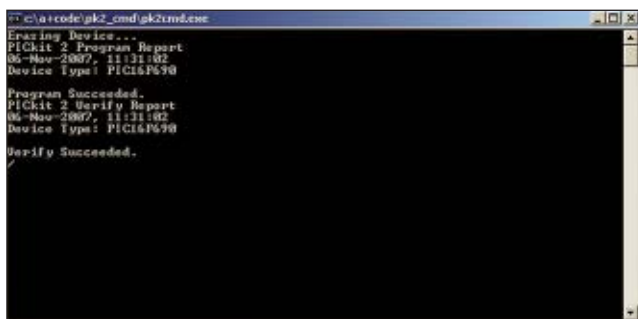
pk2cmd.exe file that was included in the zip file you downloaded. You don't have to know where it is for this step but, when you click on the "Next >" button, the screen in Figure 6 will pop up asking for the file location.

You have a choice in how you want to find the "pk2cmd.exe" executable file. You can have MicroCode Studio search for the command line automatically, or you can manually select it yourself if you remember where you put it on your hard drive. The manual option is a lot faster.

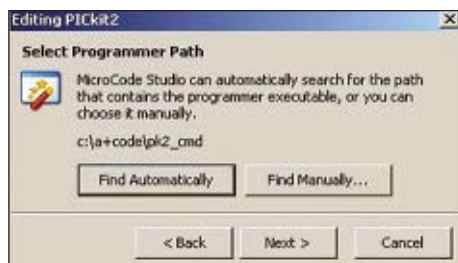
## COMMAND-LINE OPTIONS

The next step I'm going to describe is the most critical and the most difficult, because these are the command-line options that will transfer the PIC you are using and the .hex file that the compiler just created

■ FIGURE 7. Command Line Option Window.



■ FIGURE 8. The pk2cmd.exe Programming Screen.



■ FIGURE 6. Find the PICKit 2 Command Line.

to the PICKit 2, prior to starting the PICKit 2 command-line executable. The command-line options include both the PICKit 2 and MicroCode Studio format options, combined. It took me several tries to get this right. The line you enter may vary from what I show below, depending upon how you want to use the PICKit 2.

**-PPIC\$target-device\$ -F\$hex-file  
name\$ -E -M -Y -Y**

The "Readme for PK2CMD.txt" file that downloaded with the "pk2cmd.exe" file explains all the PICKit 2 command-line options. I highly suggest you read this over. The command-line options I ended up with are shown entered into the screen in Figure 7. Let me explain my choices.

The -P option selects the PIC, but I wanted MicroCode Studio to pass that on from its selection window. MicroCode Studio offers that detail as a parameter "\$target-device\$," but it doesn't include the "PIC" in front of the number (e.g., it shows simply "16F690," instead of PIC16F690) so you have to type that in. This gives us the "-PPIC\$target-device\$" part of the command-line option.

I'm using the PICBASIC PRO compiler, and the -F option selects the .hex file from the compiler created. MicroCode Studio offers the path to the compiled and assembled .hex files through a parameter called "\$hex-filename\$." This part of the command line thus becomes "-F\$hex-filename\$."

The other command-line options are where you may modify the setup that

I have. I first added the -E option, which directs the PICKit 2 to erase the PIC first, before loading a new program. Then I added the -M option, which directs the PICKit 2 to program all locations, including program memory, the configuration, the EEPROM, and the ID memory. You can do these separately if you want just the program memory. The different command-line options for these other choices are explained in the "Readme for PK2CMD.txt" file.

The -Y is the last option I chose to include in my command line, and it verifies the device. I would have thought -V would have been for verify, but it does something else, which is another reason why I recommend reading the README file. As with the -M command, I chose to have everything verified. The program memory, configuration, EEPROM, and ID locations are all verified. You can do these individually, as well.

You will notice that I added a second -Y to the end of the command line. This is strictly for a delay. When the command line starts from within MicroCode Studio, it actually opens a separate DOS command-line window as shown in Figure 8, then performs the erasing and programming routines, and then verifies the locations. After the verification is complete, it quickly closes the DOS command window that it had opened. The problem is it closes the DOS command-line window so quickly, that I could not see if the "Program Succeeded" and "Verify Succeeded" messages were displayed. Adding the second -Y provided enough delay to allow me to read them.

I later found out that the -M command actually erases the part and verifies it also. So a "Program Succeeded" message means the part was also successfully erased and verified. I prefer to see the actual "Erasing Device" and "Verify Succeeded" messages so that is why I still include the -E and -Y. Therefore, if you add all this up, my command line actually erases the part twice, programs in



once, and verifies it three times. Overkill, but I get the messages I want.

That's it. Follow these steps and you should have your PICkit 2 running within MicroCode Studio, with the PICBASIC PRO compiler, and have a one-click, compile and program solution . . . or will you? If everything is perfect, then you will. However, there are always a few gotchas when trying to do something new like this.

## NOTHING'S PERFECT

If, for some reason, the PICkit 2 command-line interface has a problem, then an error message will appear. However, the window will close so fast that you won't see it. I haven't figured out a way to add a delay to the error messages since they are displayed automatically. This is one of the shortcomings to the way the command-line program is written.

If you see the DOS command-line window open and then close quickly, assume you have an error. To view it, you have to open the command line yourself and run the pk2cmd.exe file from the DOS command line (if you know how to do that). Only then can you see what the error is. The next step is figuring out what the error(s) mean(s). Here are a few tips you'll need to make sure you are successful in getting this to work.

Make sure your PICkit 2 has firmware level V2.10.00 or later, otherwise it won't work with the command-line option. This is stated in the README file. You can update the firmware through the command line interface, but I find it easier to use the GUI interface that comes with your PICkit 2.

Make sure your board with the PIC installed is powered separately from the PICkit 2 if you want it to run after programming. Even though the PICkit 2 can power a circuit after the chip has been programmed, the command-line option doesn't support that feature. The PICkit 2 under command line control will only power the board during the programming operation.

Once you have successfully programmed and verified your PIC, and have seen the success messages in the DOS command line window, you will see the DOS window close but your program will not run in your circuit. This is because the PICkit 2 is holding the reset or MCLR pin low, keeping the PIC in reset mode. You have to disconnect the PICkit 2 from the circuit to release the MCLR line, and then your program should start to run. You can easily add a program/run switch to the MCLR pin on your circuit to make this easier.

I'm sure the command-line interface will get updated to correct a lot of these quirks, as this is only version 1.00. I'm also told that the source code may be made public, so all of you great PC programmers out there may be able to do a lot to improve this command-line interface. As it stands, it can easily be placed in a batch file for automatic programming if you have several prototypes to build. The options are endless for this great addition to the PICkit 2.

## CONCLUSION

As you can see, the PICkit 2 just gets better and better. Now, the ability to use this with a third-party IDE such as MicroCode Studio opens up a whole new arena for the PICkit 2. This won't give you the DEBUG support that the PICkit 2 offers. That requires you to run the PICkit 2 from the Microchip MPLAB IDE but, for many beginners, all they want is an easy path to write a program and one click compile and program, so this is a great USB option to do this for a really low cost.

There are other USB PIC MCU programmers that have a command-line interface, but I still like to use the PICkit 2 programmer because of the low cost and simple six-pin interface. It's easier to build that six-pin interface on a circuit board or even a bread board. I have been searching the web for a DOS version ever since I first started using the PICkit 2. Hats off to the team at Microchip who made this happen. This adds another step to making it easier for beginners to get started programming Microchip microcontrollers. As usual, email me your comments and questions. I look forward to hearing about how well this worked for you. See you next month. **NV**

## CONTACT THE AUTHOR

■ Chuck Hellebuyck can be reached at [chuck@elproducts.com](mailto:chuck@elproducts.com)

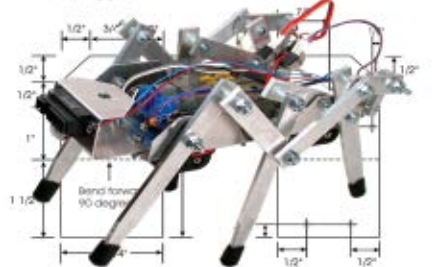


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# ROBOTICS

## PERSONAL

### UNDERSTANDING, DESIGNING & CONSTRUCTING ROBOTS & ROBOTIC SYSTEMS

■ BY VERN GRANER

## ROBO SPIN ART — Retro Art Meets the Joystick Generation

**THE VENERABLE SPIN ART MACHINES** popularized in the 1960s and 1970s created funky, psychedelic artwork many of us remember from the carnivals and county fairs of our youth. Simply put, “spin art” is created when paint is dropped on to a rotating paper, allowing centrifugal force to make streaks of color. The RoboSpinArt machine updates this concept by making spin art attractive to the so-called “joystick generation” of today while also adding on features to the original design.

### REELING IN THE YEARS

When I was about 10 years old, a Halloween carnival came to a park near my house, and they had a spin art booth in their Midway. The spin art machines they used were the pinnacle of simplicity — a table with a hole cut in it for a bucket, and a motor in the bottom of the bucket with a small bracket to hold a paper card. The operator would turn on the motor, and the kids would use various ketchup bottle type containers to drip different colors of paint on the card

as it spun. After a few minutes, the operator would turn off the motor and hand you the finished “painting.” At 10 years old, I thought this was amazingly cool!

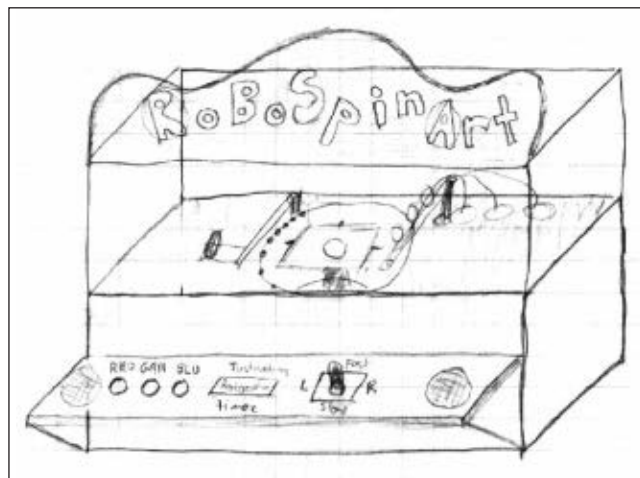
Flash-forward a few years (okay, more like decades) and I’m in my garage cleaning up a bit with my 10-year-old son Nicholas when I came across a box with various relics of mine from that time. One item was a slightly faded cardboard card with the classic spin art swirls on it. I showed it to my son enthusing about how it was made, how much fun it was to make, and how cool it looked. Giving me the

patented “uh ... sure Dad” look, he said it sounded “okay but kinda boring.” I wrote off his disinterest at the time, but his reaction stayed in the back of my mind. What was it that made the difference? Why was it interesting to me at 10 years old, but not to him?

### LIVING IN A DIGITAL WORLD

After the thoughts incubated in my head for a bit, it occurred to me that my son isn’t used to dealing with devices that don’t have some type of digital user interface. Video games, the TV remote, microwave oven, computer, cell phone, and MP3 player ... all the things he uses daily and understands thoroughly have some version of a digital user interface. Buttons and joysticks are usually accompanied by sound effects, LCD displays, voice prompts, and in many cases, a rockin’ stereo soundtrack. Although as a kid of 10 I was fascinated by the simple spinning colors of the spin art machine, my 10-year-old son was not nearly so impressed. On reflection, I wondered if it was the spin art that failed to ignite his interest or the interface to the spin art that was a barrier. If we updated the interface, would the spin art suddenly become interesting again?

Coincidentally, all this occurred about the same time that First Night Austin (a local, family-oriented New Year’s celebration) started soliciting artists for proposals for their annual



■ **FIGURE 1.**  
First sketch of the RoboSpinArt machine.



First Night Austin street celebration. Thinking this the ideal venue for such an amalgam of retro art techno geekdom, I spoke with a few of my regular cohorts at The Robot Group and decided to propose "Robo SpinArt" for First Night. Since I'd already been thinking about making a spin art machine of some type, I sketched up some plans and features (Figure 1) and sent in a proposal.

After weeks of waiting for an answer, I just decided to go ahead and start on the machine myself. I figured if First Night did say yes, I would need to have a good head start to ensure the unit would be ready by New Year's Eve. If they didn't approve the proposal, at least I would be on my way to having a cool new project.

## MAKING A LIST ... CHECKING IT TWICE ...

Using the notes from my sketches, I outlined the functions of the machine. I started by going over the things the original old style spin art machine had and compiling a list of the things I needed to do to "update" the machine for the "Joystick Generation."

- *Limit the ammo:* One of the first things to do to improve the machine would be to limit the amount of paint available (i.e., 30 drops or shots of paint). By making sure the kids only had a limited amount of paint ammo, I could eliminate paper saturation as a problem and have a much better chance of the finished piece having that classic spin art look. Not only would this reduce the chance of someone making a mess of their paper, it would also cut down on the amount of paint consumed by the device in the course of its operation, thereby keeping operating costs down. This approach had the added advantage of reducing the amount of time kids had to wait to use the machine since once your ammo was gone, your turn was over.

- *Limit the time:* By putting a count-down timer on the machine, a sense of urgency is created. If you only have,

say 30 seconds, you need to start painting quickly. This not only makes it exciting, it helps with the throughput of the machine. Kids who carefully place their shots would know exactly how much time they have to aim and fire their paint. I could also use this as a way to calculate the maximum throughput when trying to determine how many kids could be served and how much paper should be brought to a given event.

- *Arcade style controls:* The paint firing would be controlled by a series of arcade quality buttons that could be used to fire the paint shots. An arcade style joystick would be used to aim where the paint would fall. Not only would arcade-style controls make the machine more robust, they would also be familiar to the kids and give them an intuitive interface to operate the machine. Each of the buttons also had a colored cover that would light up to indicate the pump was on and what color of paint would dispense when a given button was pressed. A paint gantry (reminiscent of a record player tonearm) would move in an arc over the bucket to allow the kids to aim at different parts of the paper.

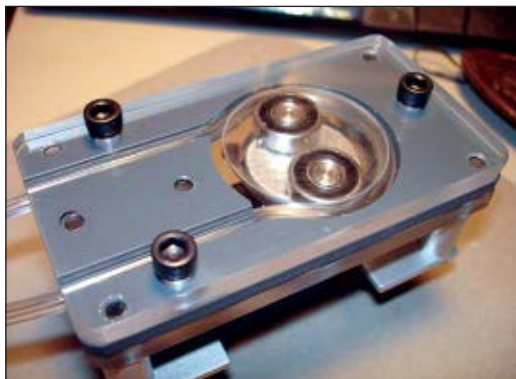
- *Speed control:* As a new twist on the old spin art design, I thought that since I had both UP/DOWN and LEFT/RIGHT controls in the joystick, I could use the UP/DOWN motion to control the speed of the motor that spins the paper. Pushing UP on the joystick would accelerate the paper causing the paint tendrils to become thinner and the colors could become more translucent. Pushing DOWN would make the tendrils appear to be thicker and the colors more vibrant since less paint would be thrown off the paper. Also, accelerating and decelerating the motor right as you drop a paint shot could alter the paint trajectory as it moved outward on the paper. This would cause effects such as swirling or bending paint tendrils. Having this sort of hidden functionality was reminiscent of special combo moves in video games.

- *Freeze frame:* Another common

problem with the older spin art machines was the inability to see your artwork until the motor stopped spinning the paper. By the time the motor had stopped, it was too late to add paint to a blank portion of the paper or add a few more paint drops that might improve the final piece. To allow the kids to preview their work, I planned to add high-intensity white LEDs pointed down into the bucket to act as strobe lights. These lights would be timed by an encoder on the motor shaft that, when activated, would blink the LEDs one time per rotation of the paper. This would freeze the image and let the progress of the painting be inspected while it was being made.

- *Video broadcast:* As an added touch, I thought it might be interesting to have a video camera in the top of the machine pointing down into the bucket so people in line could watch as the spin art was being made. This would also help them understand the operation of the machine, reducing the amount of instruction required when it was their turn.

- *Card logo and inscriptions:* When I was a boy, it was a standing rule in my household that when we attended an event and the event offered souvenirs, we were only allowed to choose one that had the event or location written on it. As it was likely that the spin art machine would be taken to various events, I thought it would be neat if I could continue this tradition by inscribing text and placing a graphic logo on each card. By limiting the travel of the paint gantry, I could protect the center of the card from being painted, thereby leaving space for this inscription. It would then be a simple matter to pre-print cards for an event with a logo and some descriptive text. However, there was always the problem of printing too few or too many cards for a given event (leading to wasted cards). To mitigate this, I planned to print some cards with a generic graphical logo (i.e., a birthday cake), and then add text to the logo at the time of painting (i.e., "Happy Birthday Sami!"). This would make creating custom cards easy and



■ FIGURE 2. Peristaltic pump prototype.

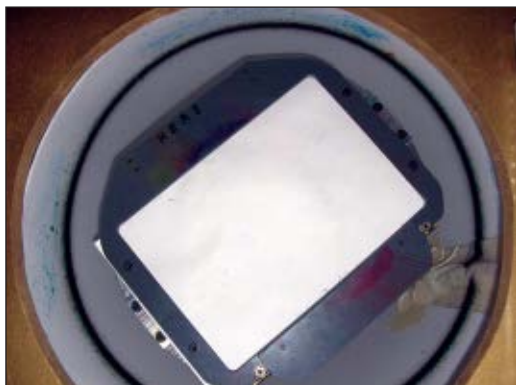
reduce wasted cards. Parallax had recently made available a serially controlled ink jet kit that, when placed on a movable arm, could be lowered into the bucket just before painting to inscribe text around the logo.

- *Sound and music:* Lastly, the machine would need a pair of stereo speakers and a nice, powerful audio amplifier in the box so that sound effects and the rockin' stereo soundtrack would accompany each turn on the machine. This would help to complete the arcade experience, entertain the person painting, and also draw in a crowd to see what all the excitement was about.

## WHERE TO START?

So, now that the requirements were all lined up, it was time to start making things. The first item we attacked was the method for dispensing paint. In a traditional spin art machine, the kids are handed a ketchup-style bottle full of paint. Most

■ FIGURE 4. The "spinner" frame with snap-down PVC cover to hold paper.



■ FIGURE 3. Final peristaltic pump design; loaded and ready to paint.

children will simply dump as much of it as they can on to the paper resulting in a soggy, saturated, monochromatic mess. In order to alleviate this problem, I needed to have a pump that could be triggered to dispense a precisely controlled amount of paint. I explored a number of pump systems but finally settled on the peristaltic pump design.

Peristaltic pumps work by using a roller bearing to pinch a section of flexible hose (creating a movable "seal") and then moving the pinch point away from the source of the liquid and towards its destination. This creates pressure in front of the pinch point and a vacuum behind it. This style of pump is commonly used in food preparation and the medical industry because the pump does not come into contact with the liquid being moved.

This is also perfect for pumping paint because, not only can you very precisely control the amount of paint moved, but you would not have to clean paint out of the pumps at the end of the day. It seemed a peristaltic pump would be perfect for operation by a microcontroller as I could deliver a precise shot of paint with each press of a button.

To make the peristaltic pumps, I turned to Rick Abbott, a talented "old school" machinist and long-time member of The Robot Group. He hand-built a prototype peristaltic pump out of clear Lucite with aluminum pinch rollers and a continuous motion servo motor. Although beautiful to behold, this first pump didn't work well at all.

Upon careful observation, a number of things were apparent. First, the shaft of the servo motor was plastic, and as the pinch roller went past the unsupported section of the hose guide (Figure 2), the servo shaft would bend and the lack of pressure by the roller against the tube would cause the pinch seal to fail. When used to pump water, this prototype would draw the water about a quarter inch up the tube; then, when the seal broke, the water would fall back down.

After some head scratching, Rick went back to his shop and emerged a few days later with a new design that had three pinch rollers, a solid steel shaft to support the rollers, and dual bearings to keep the rollers square in the housing. This way, the servo motor only had to provide rotational torque, and the dual bearings kept the pinch rollers in constant pressure against the tube. He brought the new pump over to my house and we tried them out on a cup of water. They worked beautifully! He then set to work making a set of four matching pumps for the machine (Figure 3).

With the pumps finished, Rick designed a bracket to hold the paper in the bucket. He re-purposed an old pump motor and machined an aluminum frame to hold the paper. We tested this first design and discovered that when paint is applied to the top of a paper card, the pulp expands and the card can bow upwards. This



■ FIGURE 5. Old cabinet becomes a spin art base.



■ FIGURE 6. Bruce Tabor working on the top for the box.

turns the card into a rudimentary wing which made it fly right out of the frame! (See the Resources for a video about the RoboSpinArt machine that includes the paper launching into the air!).

This was one of many lessons we learned while building this machine. Rick re-designed the aluminum frame to have a snap-down PVC plastic cover to hold the paper in place and in testing, the paper stayed put for painting (Figure 4). So, now we had the basic mechanical parts for the machine. We just needed something to put them in.

## BOXING DAY!

As I'm not too handy in the wood-working arena, I reached out to another friend of mine who does carpentry for a living. I went out to see Bruce Tabor. Bruce has a fully-equipped carpentry shop and he said he could help out with the project. I brought my sketches and hoped he would be able to help convert them into reality. Bruce happened to have a cabinet base left over from a project and offered to convert it into the chassis for the RoboSpinArt machine (Figure 5).

After a number of hours cutting the slanted top, adding some channels for the Plexiglas, and cutting a hole for the all-important bucket, a spin art machine began to take form. (Figure 6). I brought the raw wooden box home and placed a few parts in it. It was really beginning to look like a cool vintage arcade game (Figure 7)! Before I started permanently mounting the controls, it would need a bit of decorating. I contacted Denise Scioli, a local Austin artist (and of course, fellow Robot Group member) and she took control of the decorating. With the help of some friends, she sanded, painted, and decorated the box with a cool, retro-tech, pseudo steampunk finish (Figure 8).

## HELLO WORLD!

Now that I had the box all ready,



■ FIGURE 7. Finished box takes up the whole kitchen table!



■ FIGURE 8. The box after paint and decorations.

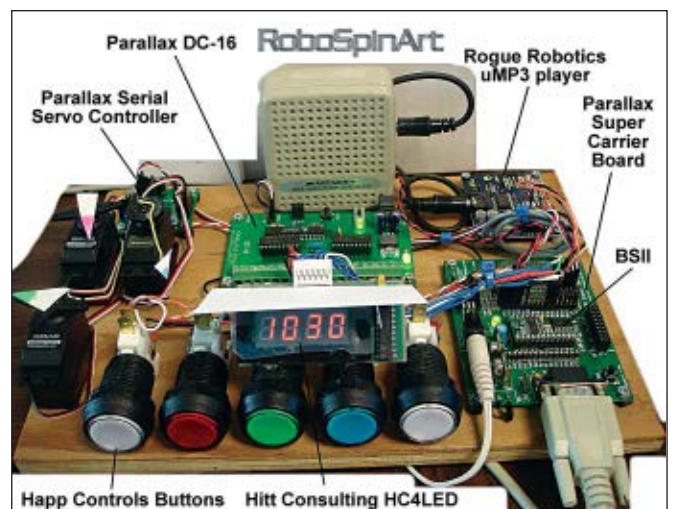
I mounted the bucket, the controls, and the pumps. With most of the hardware done, it was time to get busy bringing the monster to life by writing some software. I started small, first building a prototyping platform that would allow me to start writing and testing software for the various component parts (Figure 9). This small board had all the systems I expected I would need including:

- Parallax BASIC Stamp II
- Parallax Super Carrier Board
- Parallax Serial Servo Controller
- Rogue Robotics uMP3 Player
- EFX-TEK DC-16
- Hitt Consulting HC4LED display
- RadioShack audio amp
- Arcade buttons from Happ Controls

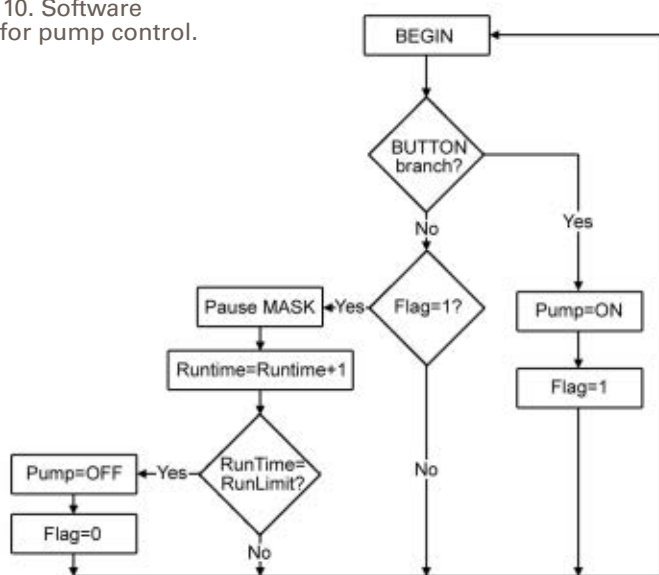
I wrote some general code blocks that would let me read the buttons, run the servos, change the values shown on the LED display, turn the button lights on and off, and trigger sound effects. I spent lots of time getting the logic straight, which for me means building flow charts of different programming methods to track the logic (Figure 10).

■ FIGURE 9. Software prototyping board Rev 1.

Once I had the basic functionality, I brought the board out to Dorkbot Austin (see Resources section for more info on "Dorkbot — People doing strange things with electricity") for a bit of a preview (Figure 11). The reaction was wonderful! The kids enjoyed playing with the board, even though all it did at the time was blink lights, make sounds, and spin servos! Lots



■ FIGURE 10. Software Flowchart for pump control.



(A)

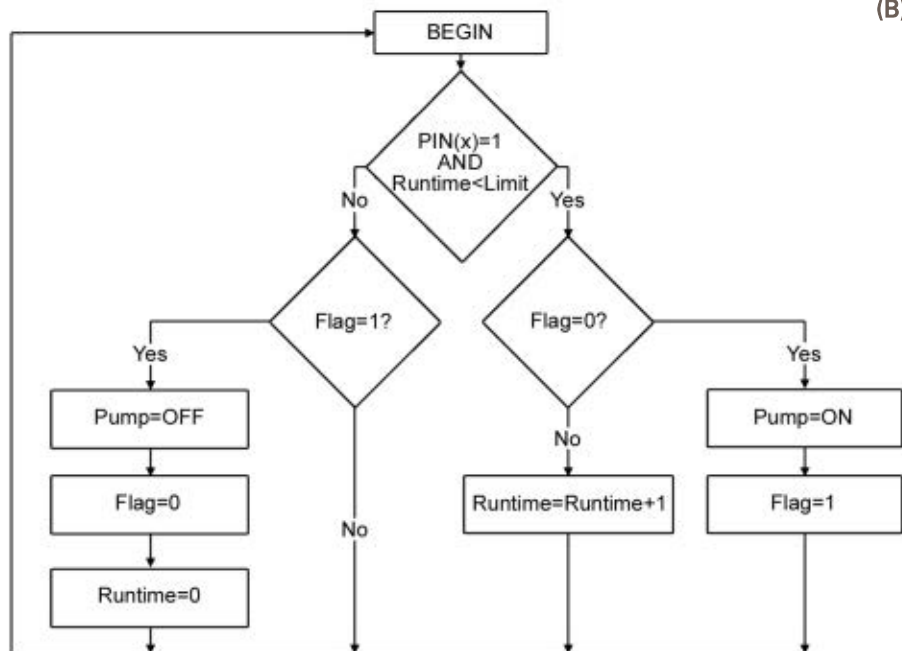
of people were very interested in seeing how the final product would turn out.

## IF IT DON'T FIT, DON'T FORCE IT

Now that I had the basic building blocks of code, I started to try and string them together to get true game-style operation. For starters, I needed to track four paint shot buttons, four joystick directions, the number of pumps ran, which pumps were on, when they should be turned off, what sound effects were playing, and how much time was left before the game was over! I very quickly realized I was not going to make all this fit in my trusty BASIC Stamp II chip.

Luckily, I had a Parallax BSIIp24 chip. This chip has eight memory slots. I could fit eight times the code into this chip and it was three times faster than the BSII. It would be even better at handling all the complex tasks that had to happen (in what appeared to the end user) as being in parallel. This turned out to be a very good choice as I soon discovered that, not only did I need to make the game work as described above, I had to build other modes of operation such as "Game Over," "Maintenance," "Setup," and "Attract" modes. In my final design, each of these options received its own slot in the BSIIp24.

Though the BSIIp24 had more memory than the BASIC Stamp II, it still had the same number of pins. With all the features I was adding, I



(B)



■ FIGURE 11. RoboSpinArt designs and software prototype board presented at Dorkbot Austin.



■ FIGURE 12. Software prototyping board Rev 2.

was rapidly running out of I/O on the chip. I turned to my friend Paul Atkinson (yet another Robot Group member) to help with the overhaul of the prototype board. Paul designed and etched a PCB to hold a 74LS165 input multiplexer to handle



■ **FIGURE 13.** Jonathan Coulton making a RoboSpinArt — In September 2007, we brought the RoboSpinArt machine to the Jonathan Coulton concert at the Cactus Cafe in Austin. The fans waiting in line got to make spin art and then Jonathan came out and made one himself while the machine blasted Code Monkey! A link to a video is in the Resources section where Jonathan makes a spin art and then talks about the machine while onstage!



■ **FIGURE 14.** P.Y. Hung and Denise Scioli at the “build party.”

the pump buttons and the joystick switches, and we added a Parallax Serial LCD display to show menus and settings in the Setup and Maintenance modes. We finished up by adding a second Rogue Robotics uMP3 player so we could have music and sound effects happen at the same time (Figure 12).

## MUSIC TO MY EARS

Now that the demo board had proven successful, I needed to start on the sound effects. I contacted a good friend of mine, John Richter, who is (among other things) a rather talented composer. He has some very cool digital keyboards and he agreed to make some “sci-fi” sound effects to accompany the actions of the machine. Over a course of a few days, John sent me about 60 different sound effects from which I pulled 16 to use for the final sounds. Now, I just had to find that rockin’ stereo soundtrack.

I had recently discovered Jonathan Coulton (some of you may be aware of his hit song “Code Monkey”), a musician with a huge online following and some very rockin’ quirky tech-oriented music that I had listened to rather extensively while I worked on the software for the machine. I sent him an email asking if I could use his music for the soundtrack part of the project and included some details about the machine. Surprisingly, I received an almost immediate reply that not only gave me permission to use the music but declaring the RoboSpinArt machine “so awesome!” (Figure 13).

## IF ONE IS GOOD ...

Now that I had the soundtrack done and most of the code written, it was time to put the parts into the actual machine and start testing. I had a build party at my house one weekend and invited some of the roboteers from The Robot Group (Figure 14) over to assist in putting together the prototype. We spent the afternoons transferring the parts from the proto board into the actual machine and I spent the evenings building and soldering the custom wiring loom (Figure 15). By the end of the weekend, I had a baseline operational RoboSpinArt machine with all the parts mounted (Figure 16). Which is good because about that time we finally heard from First Night Austin.

Seems they really liked the idea of a RoboSpinArt machine. In fact, they liked the idea so much that they wanted to know if we could build two of them for First Night! Oh, and while we were at it, could we bring a machine down for a little PR event at city hall where the mayor of Austin would be announcing First Night Austin at a press conference ... this weekend? Lucky for us, we had started early so we were able to show off a fully operational RoboSpinArt machine (Figure 17). At the press event, several people took turns

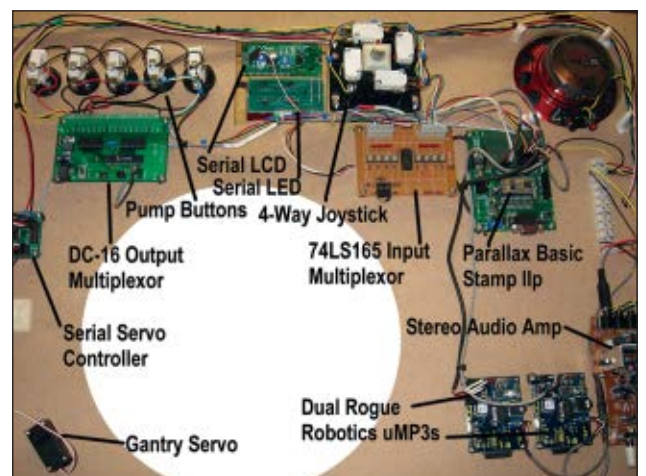


■ **FIGURE 15.** The author building the wire loom.

making spin art while the cameras rolled (Figure 18), and I had the opportunity to describe the machine for some reporters (Figure 19).

## ON YOUR MARK, GET SET ...

The next weeks were spent pulling late nights and building as much as we



■ **FIGURE 16.** Parts layout after mounting.



## RESOURCES

■ RoboSpinArt website  
[www.RoboSpinArt.com](http://www.RoboSpinArt.com)

■ The Robot Group  
[www.TheRobotGroup.org](http://www.TheRobotGroup.org)

■ First Night Austin  
[www.FirstNightAustin.org](http://www.FirstNightAustin.org)

■ Dorkbot Austin  
<http://DorkbotAustin.org>

■ Jonathan Coulton on RoboSpinArt video  
[www.youtube.com/watch?v=WcovKOzvRTc](http://www.youtube.com/watch?v=WcovKOzvRTc)

■ "RoboSpinArt — Concept to Concrete" video  
[www.youtube.com/watch?v=bEKPDnCyZk](http://www.youtube.com/watch?v=bEKPDnCyZk)

■ "Ink jet gantry — proof of concept" video  
[www.youtube.com/watch?v=1VzlrBQeaQ0](http://www.youtube.com/watch?v=1VzlrBQeaQ0)

could as quickly as we could trying to make a complete second RoboSpinArt machine from scratch. Rick made a second set of peristaltic pumps (again all by hand) and another spinner for



■ FIGURE 17. The Robot Group with the RoboSpinArt machine at Austin City Hall.



■ FIGURE 19. The author interviewed by KUT radio.



■ FIGURE 18. The press had fun shooting the spinning colors.

preparation, and all the other bits needed to finish the machine.

In the end, we only ended up with two unrealized features: the strobe light sync circuit and the ink jet painting gantry. Though we did get the ink jet gantry mounted (Figure 20) and in preliminary tests we could get it to print the

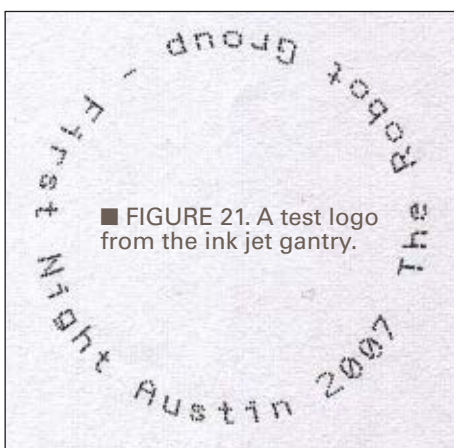
circular logo (Figure 21), we found we would need a more precise motor speed controller to make sure that the ink jet wouldn't underwrite or overwrite the text due to variations in speed of the motor that spun the paper. The solution (a feedback enabled motor controller) would require us to rework the shaft sensor to provide the feedback. Unfortunately, it would also require a reworking of the strobe light timing circuit to process this new signal. There just wasn't time to get it done, so the strobe effect and the ink jet would have to wait.

For all intents and purposes, when the day arrived, we had two fully operational RoboSpinArt machines (Figure 22) ready for First Night. We set up on the day of New Year's Eve in front of City Hall at 10:30 a.m. By 11:00 a.m. we had a line of people waiting, so we fired up the machines and started painting. We had a steady line of folks till 11:30 that night (Figure 23)! The machines ran non-stop (only changing out the operators) for a full 12+ hours, going through well over 1,600 cards without a single system failure. It was an amazing success! Little children, older folks, parents — everyone loved making spin art!

■ FIGURE 22. The author with two working RoboSpinArt machines.



■ FIGURE 20. The ink jet gantry.



■ FIGURE 21. A test logo from the ink jet gantry.





## ROBOSPINART OPERATION

To operate the RoboSpinArt machine, a person behind the unit (the operator) will place a piece of paper on the turntable. Once the paper is in place and an artist is ready to begin, the operator presses a start button on the back of the cabinet. At this point, the RoboSpinArt machine will drop a print head down onto the paper and inscribe a circular message onto the paper. After the inscription, the turntable will spin up to the accompaniment of music. Once up to speed, the artist will be verbally signaled with a countdown of "three ... two ... one ... PAINT!" At this point, they may choose to:

- Move the paint gantry left or right with the joystick.
- Increase or decrease the speed of the turntable with the joystick.
- Dispense paint using the pushbuttons.
- Activate the strobe light.

Once 30 paint shots or 30 seconds has elapsed (time and paint shot values are adjustable by the operator), the turntable will spin down and the operator is signaled to remove the painting.

The operator unloads the finished art and then reloads paper for the next artist. When not actively painting, the RoboSpinArt will revert to "attract mode" where sounds and lights will entice people into trying their hand at creating art.

With a typical turn-around time of 1.5 minutes per artwork (20 seconds to load the paper, 20 seconds to inscribe the message, 30 seconds for the artist to paint, and 20 seconds to remove the paper and hand to the artist), each RoboSpinArt machine can entertain approximately 40 people per hour.

## AND ... WE'RE BACK!

Since that night, the RoboSpinArt machines have been a staple at Robot Group events. We even had one of them up and running during Maker Faire Austin (Figure 24). The folks at First Night were also very happy with the RoboSpinArt performance. In fact, they've booked us for a return engagement! At this year's First Night Austin, our two RoboSpinArt machines will flank The Ponginator (see *Nuts & Volts* December '07) which will be making its inaugural outdoor appearance. We

■ FIGURE 24. The RoboSpinArt machine at Maker Faire Austin.



## CONTACT THE AUTHOR

Vern Graner can be contacted via email at [vern@txis.com](mailto:vern@txis.com).

plan to have the strobe light function and the ink jet gantries added to the RoboSpinArt machines by then so, if you're in Austin on December 31, 2007, feel free to come by and make some RoboSpinArt with us! **NV**

■ FIGURE 23. The crowd formed two lines at First Night Austin.



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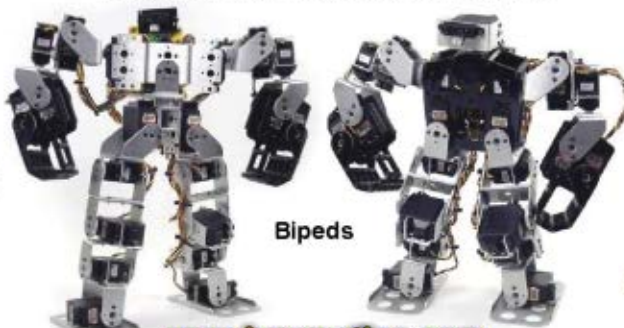
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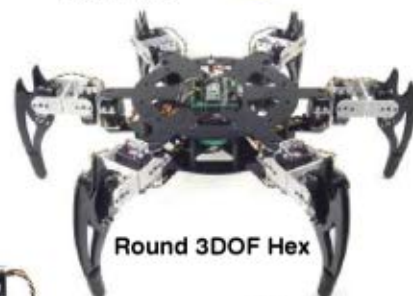
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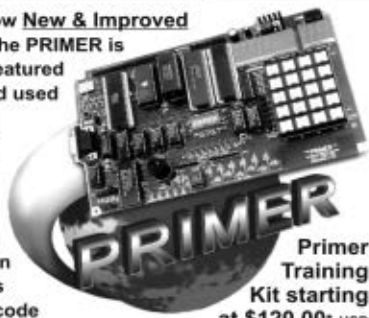
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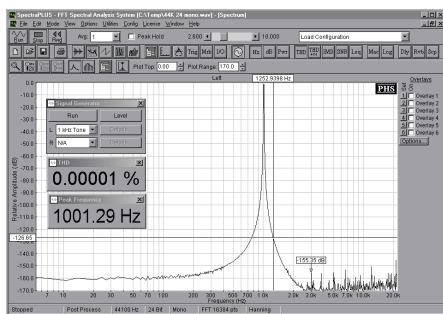
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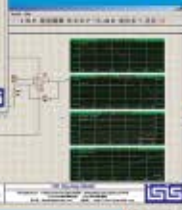
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■ BY FRED EADY

# MANAGING THE REAL WORLD

**NO MATTER HOW POWERFUL A MICROCONTROLLER may claim to be, a microcontroller by itself cannot do everything in a real-world, I/O-oriented embedded system. For instance, I don't know of any microcontroller that can directly drive a one ampere resistive or inductive load directly from one of its I/O pins. That means if you're working on putting together a microcontroller-based system that will interface to motors and relays, a great deal of your design time will be expended on the I/O interface hardware.**

**T**he same holds true if your microcontroller has to switch high currents. You'll have to put some heavy duty electronic hardware between the microcontroller's multi-milliampere I/O pin and the amperage hungry I/O device at the other end. Amperage is not the only worry you have. You can't reliably drive a 12-volt relay coil with a raw 3.3-volt or 5-volt microcontroller I/O pin. And, 12 volts may be a drop in the bucket if you've got an I/O device that wants to see a 60 volt source. What about controlling a standard household AC device? Can you imagine driving a microcontroller I/O pin with 120 VAC? Smoke on the water.

Okay, suppose you've figured out a way to get those high voltages and currents under control. Now, in addition to wrangling the voltages and currents, you have to accurately read temperatures! I'm not talking room temperatures that you would normally take with a temperature sensor like the LM35C. Your temperature data will originate at the point of a thermocouple.

Fortunately, every obstacle I've thrown into your Design Cycle can be easily circumvented without resorting to exotic or expensive special-purpose electronic components. In fact, we can solve every problem I've thrown out on the table with a simple order to Mouser or Jameco. If you're still reading, I'll show you how to easily drive relays, solenoids, high-current devices, high-voltage devices, and high-voltage/high-current I/O devices with a simple PIC microcontroller and everyday electronic parts. We'll also take a look at getting that thermocouple data.

## I/O BASICS

Professional athletes are drilled on the fundamentals of their respective sports. That's why they excel at what they do. Musicians practice, practice, and practice some more. That's why you buy their musical work in the form of a CD or a live performance. For us that dabble with electricity by

indirectly moving electrons about within silicon lattices, a firm grasp on the basics of I/O interfacing is as good as a LeBron James dunk on Sunday afternoon.

To understand how to drive that device on the other end of your microcontroller's I/O pin requires that you understand just what that microcontroller I/O pin can really do. Let's use a typical Microchip PIC as an example case. The run-of-the-mill PIC can sink or source up to a maximum of 25 mA on most of its I/O pins. That's a measly 0.025 amperes per pin. The truth is, 25 mA of sink/source capability is a relatively high value as many other microcontrollers can only handle 20 mA or better and only on a portion of their pin complement. I've seen microcontroller datasheets that claim 40 mA maximum values but I personally have not put that maximum figure to the test.

If you read the fine print in those high-current I/O datasheets, the 40 mA maximum is just that — a maximum value you're not supposed to approach in normal use. Reading carefully reveals that according to the test conditions, the 40 mA per pin microcontroller can really handle 20 mA @ 5V safely. Nevertheless, I have abused my share of PIC I/O pins. I have accidentally driven PIC I/O pins above 25 mA many times. (That's something you don't want to do for any length of time.) There's nothing worse than trying to troubleshoot a "dead" PIC port pin.

If you think you can drive a bunch of 25 mA devices without any intermediate buffering, you're almost right as long as you don't exceed a total of 200 mA across all of the I/O pins you are using to drive the loads. The point I'm trying to make here is that realistically you can't drive anything much larger than an LED load on a single PIC microcontroller I/O pin. If you think in terms of each LED drawing 10 mA, you can only drive a maximum of 20 LEDs simultaneously directly from the I/O pins of a single PIC microcontroller. I've not been brave enough to try this and say I did it, and I don't recommend that you try this at home.

Most of the time, I design my I/O buffer hardware so that



the electronic switch component will sink the load current. Sinking current means that the electronic switch component being controlled by the microcontroller's I/O pin provides a ground path for the I/O device. You can easily pick out a sink configuration as the positive power source is always connected to the I/O device in a "sink = on" configuration.

In electronic terms, the opposite of sink is source. Connecting an LED's anode directly to a microcontroller's I/O pin and grounding the LED's cathode is an extreme example of sourcing current to illuminate the LED. Naturally, you would have a current limiting resistor in the mix to keep from driving the LED into darkness and/or the microcontroller's I/O pin into burnout. I've drawn up a couple of simple LED driver circuits in Schematic 1 to illustrate the difference between sourcing and sinking current using a PIC microcontroller's I/O pin.

The electronic switch component I alluded to earlier is usually a transistor or MOSFET device. We could talk for weeks about selecting transistors and MOSFETs as there are tons of these devices to choose from. In my experience, light to medium loads can be easily handled by standard switching transistors. Darlington array transistor devices can be used in high-power situations. Many of the LM723-based high-current power supply circuits you can find on the Internet use Darlington transistors in their high-voltage/high-current output stages. However, in high-current/high-voltage applications, I prefer MOSFETs.

Honestly, I prefer MOSFETs over transistors in the light to medium application area, as well. The fact is, logic-level gate MOSFET devices are designed to be driven from a microcontroller I/O pin and exhibit very low "on" series resistances, which lead to lower voltage drops across the electronic switch component and reduced heat in the electronic switch component.

Using a logic-level gate MOSFET is just as easy as using a 2N2222A switching transistor. The idea is to provide enough drive to the MOSFET gate to completely turn on the MOSFET's Drain-Source junction. Once you supply enough voltage to exceed the MOSFET's Gate-Source threshold, the Drain-Source resistance will drastically decrease allowing current to flow between the MOSFET's Drain and Source. I'll let you debate on which way the electrons flow. In

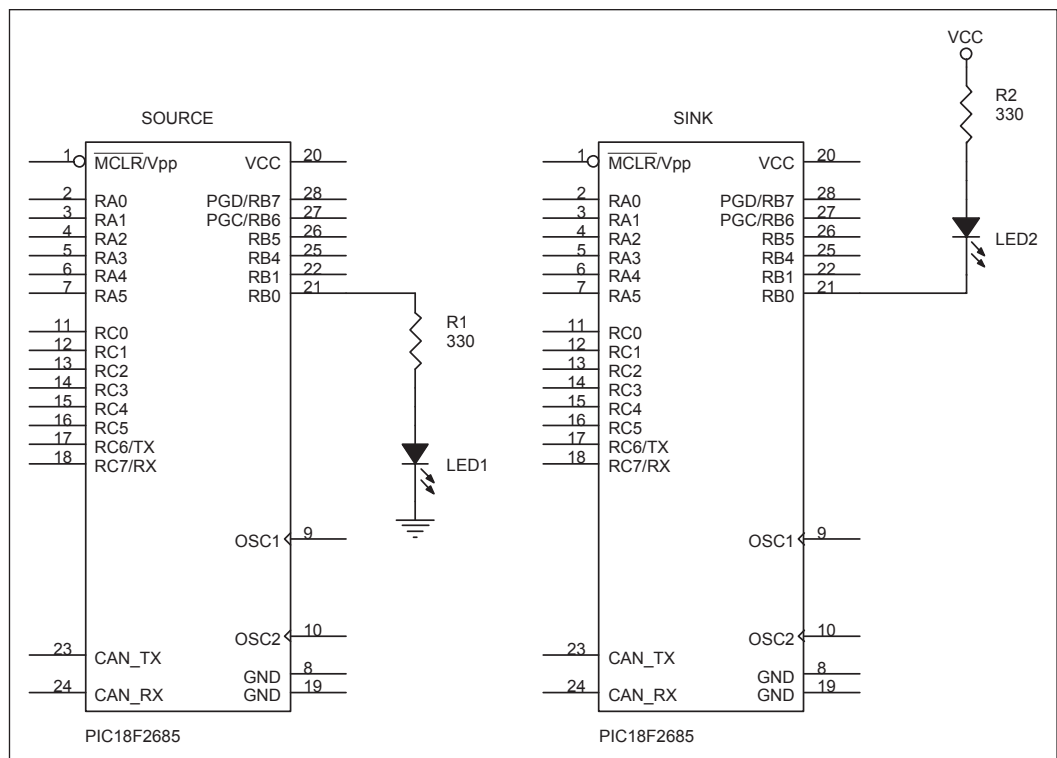
our case, it really doesn't matter as all we want to do is toggle the device at the end of the PIC's I/O pin off and on. Let's put this MOSFET switching theory discussion into practice.

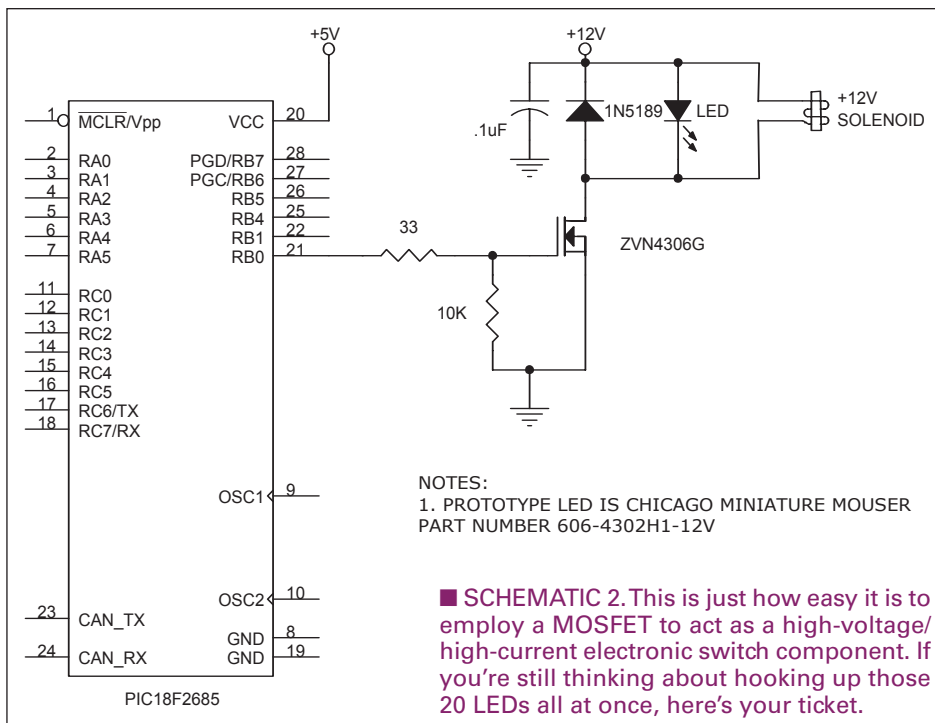
For this theory-to-hardware exposition, I've chosen the Zetex ZVN4306G as our electronic switching component. The ZVN4306G is actually an N-channel DMOS FET with a minimum Gate-Source threshold voltage of 1.3V and a maximum Gate-Source threshold voltage of 3.0V. We really don't have to worry about current drain on our microcontroller I/O pin as the ZVN4306G gate current requirements are in the dust.

For our discussion, our PIC is powered with a +5V VCC supply. So, according to the ZVN4306G's maximum and minimum Gate-Source threshold voltage specifications, all we have to do is provide a logical high state from our PIC I/O pin to the ZVN4306G's gate to open up the MOSFET's Drain-Source channel. Conversely, a low level on the ZVN4306G gate will pinch off the current flow and turn the target device off. Once the ZVN4306G is turned on, its Drain-Source resistance drops to  $0.32\Omega$ . When in the on state, the ZVN4306G can switch up to 2.1A of current continuously. The maximum switching voltage (Drain-Source voltage) of the ZVN4306G is 60V. If things get warm, the ZVN4306G is housed in an SOT223 package that can be soldered to a suitable heatsink pad on the printed circuit board (PCB).

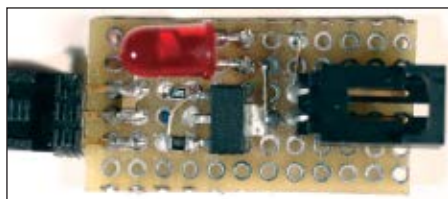
The ZVN4306G is designed into a sinking configuration as shown in Schematic 2. The ZVN4306G is acting as a high-voltage/high-current buffer for the PIC's RB0 I/O pin. In this case, we are driving a simple solenoid assembly like the one you see in Photo 1 in the sink configuration. At 12V, the solenoid coil in the fluid switch you see in Photo 1 will draw 450 mA when energized. The application that uses this fluid switch requires the solenoid to open and close the fluid passageway for 10 seconds once every hour. This is a light

■ **SCHEMATIC 1.** Applying VCC to the LED1 anode via the PIC's RB0 I/O pin illuminates the sourced LED. When RB0 provides a ground path for LED2 — which is configured in a sink configuration — you will see the light.





■ **SCHEMATIC 2.** This is just how easy it is to employ a MOSFET to act as a high-voltage/high-current electronic switch component. If you're still thinking about hooking up those 20 LEDs all at once, here's your ticket.

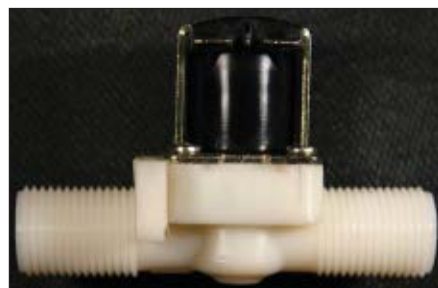


■ **PHOTO 2.** This is really rough, but it works just fine. I added the LED to provide a visual indication of the status of the solenoid valve. When the solenoid valve is energized, the LED illuminates. The LED only draws 10 mA and places no significant extra load on the ZVN4306G.

duty requirement as far as the ZVN4306G is concerned.

As a test, I decided to run the solenoid continuously until the magic smoke appeared. As it turned out, the solenoid got much hotter than the ZVN4306G, which retained its magic smoke. So, we can actually get away without attaching an external heatsink to the ZVN4306G.

I lashed up a prototype of the MOSFET buffer in Photo 2. Note that I used a specialized Chicago Miniature LED in the prototype. The prototype LED contains a built-in current limiting resistor. I like to use these LEDs in prototypes and for debugging as they can simply be soldered into the



■ **PHOTO 1.** This mechanical assembly is designed to restrict the flow of liquid when the solenoid is inactive. When the solenoid coil is energized, the solenoid plunger will retract, removing the blockage element which will allow liquid to flow.

circuit as-is. These LEDs also come in five-volt versions. The available colors are red, amber, and green. You can get these specialized LEDs from Mouser. The LED is used here to provide a visual indication of the state of the solenoid valve. When the solenoid is energized, the LED illuminates. The Chicago Miniature LED only draws 13 mA and does not introduce any significant load to the ZVN4306G.

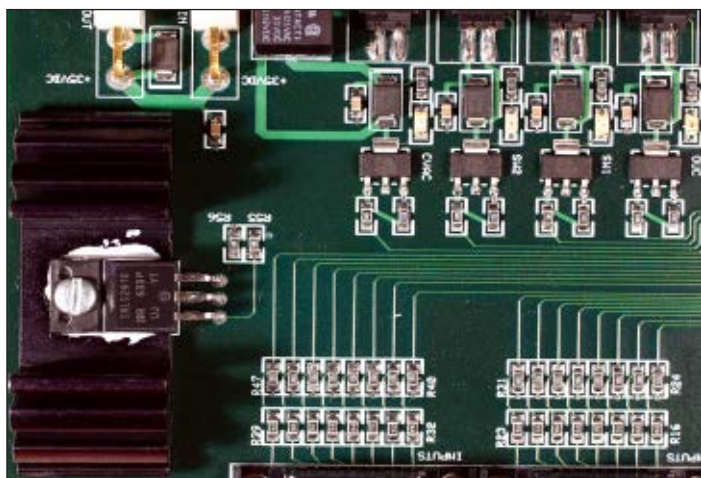
The ZVN4306G in the sink configuration can provide buffered control for a brushed DC motor or a relay coil with ease. However, even with the

ZVN4306G's high-voltage and high-current capabilities, you may find that your application needs some additional horsepower. Fortunately, we can take the basic ZVN4306G-based I/O concept we have been discussing and amplify it by employing a heftier MOSFET switching element. That's exactly what Werner von Braun did. He took the Redstone Rocket concept and amplified it to create the Saturn booster.

In this case, our ZVN4306G is the Redstone Rocket and the IRLI2910 is the Moon Rocket. The IRLI2910 is a logic-level gate drive power MOSFET. If you keep it cool, the IRLI2910 can pass up to 31A at voltages up to 100V. The IRLI2910's Gate-Source threshold voltage lies between 1.0V and 2.0V and when you turn it on with 5V, the Drain-Source resistance falls to .030Ω.

An interesting feature of the IRLI2910 is the way it is packaged. The IRLI2910 is completely insulated with a moulding compound that electrically isolates the device from the heatsink while providing a very high thermal transfer characteristic. To use the IRLI2910, simply drop it into our ZVN4306G circuit as the electronic switching component instead of the ZVN4306G.

The words that I speak in the Design Cycle column are



■ **PHOTO 3.** Teamwork — that's what this is all about. This shot shows the IRLI2910 poised in its modest heatsink alongside of a gaggle of ZVN4306G devices. The IRLI2910's job is to control a 35V @ 5A DC motor. The ZVN4306G crew is handling solenoid, relay coil, and solid-state relay duties.



well rooted in theory and high on implementation. With that, the Redstone Rocket and the Saturn Launch Vehicle are shown working together in a real-world application in Photo 3.

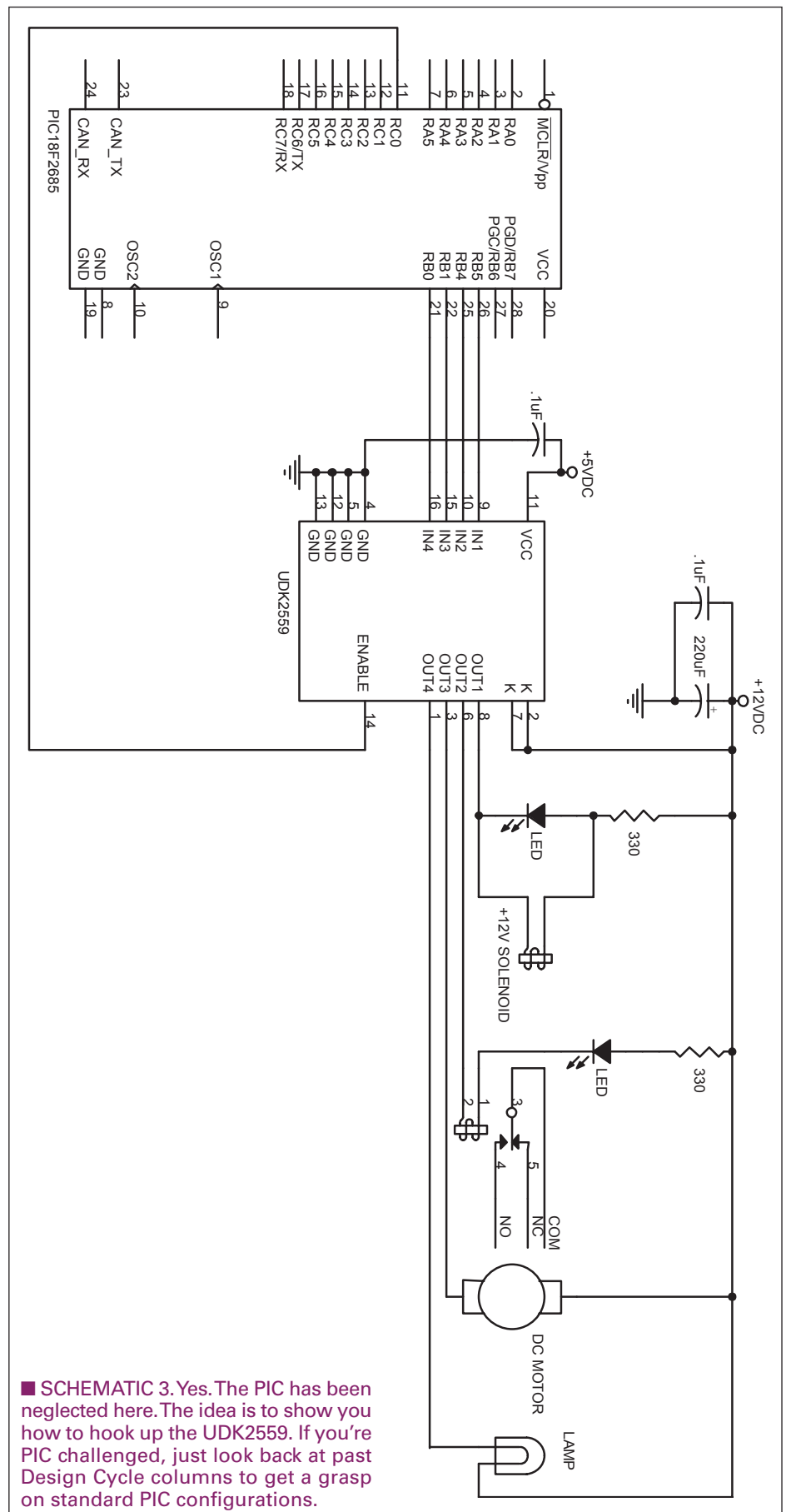
What we have just done is to assemble simple circuitry driven by PIC microcontroller I/O pins that perform very useful tasks. Each of the electronic switch components are controlled by a logical state of high or low, which emanates from a PIC microcontroller I/O pin. The results of this simple binary pattern include spinning motors, energizing solenoid valves, and switching relay contacts which, in turn, play an important role in the overall system mission. I think that you will agree that this stuff is easy. There is no rule that useful electronic devices have to be complicated.

## BASIC I/O CONDENSED

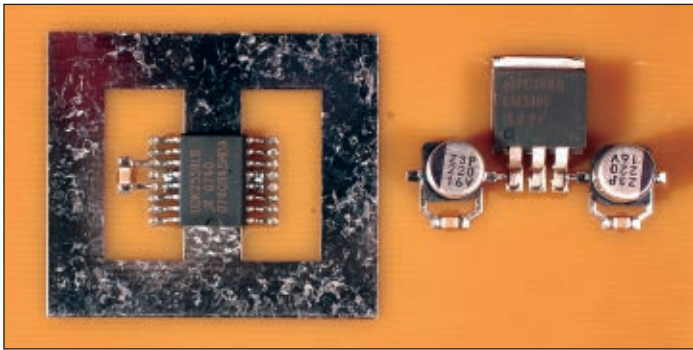
Suppose you need a quartet of ZVN4306G-like control circuits to control some low-voltage devices (less than 60V) that draw no more than 700 mA each when active. There's nothing wrong with lining up four of the ZVN4306G circuits depicted in Schematic 2 on a piece of PCB real estate. However, each ZVN4306G buffer is made up of a minimum of five components. Can I show you how you can assemble four ZVN4306G-like buffers for this application with only four components?

Behold Schematic 3 and the Allegro MicroSystems UDK2559. The four components that make up our electronic switch are the UDK2559, the UDK2559 power supply bypass capacitor, and the UDK2559 bulk device source voltage bypass capacitor pair.

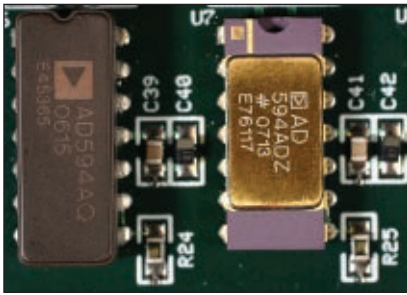
I've purposely left the PIC's particulars out of Schematic 3 as the UDK2559 connection specifics are the important part of the schematic contents. Logically, the UDK2559 is a collection of four sets of AND gates feeding four high-current bipolar outputs that can each sink up to 700 mA in their "on" state. Schematic 3 shows all of the UDK2559 drivers being linked up to the same bulk device source voltage of +12 VDC. If you need to use differing bulk device source voltages, you can divide the four UDK2559 drivers into pairs and provide one of your bulk device source



■ **SCHEMATIC 3.** Yes. The PIC has been neglected here. The idea is to show you how to hook up the UDK2559. If you're PIC challenged, just look back at past Design Cycle columns to get a grasp on standard PIC configurations.



■ PHOTO 4. The idea here was to lay down just enough copper to allow me to make point-to-point connections between the UDK2559 and the five-volt regulator circuit. Everything else is wired in as necessary. The ring of copper surrounding the UDK2559 is tied to the UDK2559's ground pins and is intended to act as a heatsink for the UDK2559.



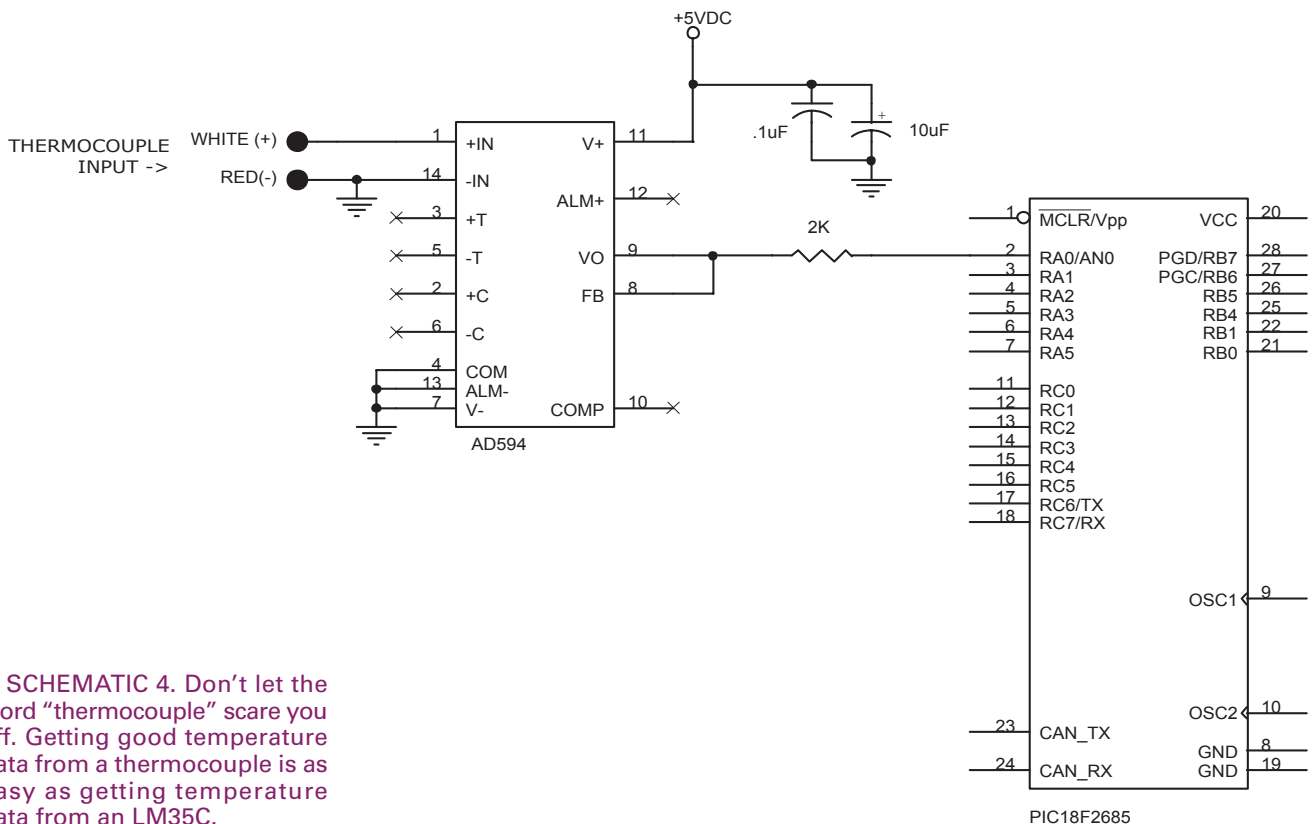
■ PHOTO 5. The trick is to keep the AD594's source voltage clean. It's also a good idea not to waste any space between the thermocouple wires and the AD594 thermocouple input pins. Notice the different AD594 packages in this shot.

voltages to the UDK2559 pin 2 K input and the other bulk device source voltage to the pin 7 K input. UDK2559 outputs OUT3 and OUT4 follow the pin 2 K bulk device source voltage and outputs OUT1 and OUT2 march to the bulk device source voltage applied at the pin 7 K input.

The UDK2559's output behaves like an NPN transistor and each bipolar output module is fronted by an AND logic gate. The UDK2559 ENABLE line is common to all of the

UDK2559's AND gates as it is tied to one of the two inputs on all four of the UDK2559's AND logic gates. Each of the UDK2559's four INx inputs are independently tied to the remaining input of the four AND logic gates. A logical low output from the respective bipolar output's AND logic gate is needed to turn on the associated NPN transistor output logic. That means we have to supply a logical high to the UDK2559's ENABLE pin in order to enable any sinking action through any of the UDK2559 output pins.

To obtain a sink condition on a particular UDK2559 output after enabling the outputs with a logical high level on the ENABLE pin, we must place a logically high level on the input representing the output we want to take to the sink state. Following standard AND logic, a logical high on the ENABLE pin coupled with a logical low on an INx pin results in a logical low on the AND gate output, which turns off the associated NPN-based output. Both the ENABLE pin and the selected INx pin must be logically high to sink current at the selected UDK2559 output pin. It's that simple. All we really have to worry about is keeping the UDK2559 cool. That is easily done by providing some ground plane area for the UDK2559 ground pins, which also act as thermal dissipation tabs. If we manage to get the UDK2559 too hot, its internal thermal limiting circuitry will shut the device down.



■ SCHEMATIC 4. Don't let the word "thermocouple" scare you off. Getting good temperature data from a thermocouple is as easy as getting temperature data from an LM35C.



I used ExpressPCB to design and fabricate a very simplistic UDK2559 prototype platform. I'll share the ExpressPCB layout via the *Nuts & Volts* website and I'll share a view of the UDK2559 in position on the ExpressPCB-generated prototype PCB in Photo 4.

I'm rather sure that I don't have to take this discussion any further. You should now be able to interface a PIC I/O pin to any voltage or current situation that may come your way.

## ANALOG ACADEMY

Did you realize that all you need to make a simple thermocouple is a bit of thermocouple wire and a twist? If you need an industrial strength thermocouple, I suggest getting one from a professional. However, if you want to experiment with thermocouple technology, just get yourself some Type J thermocouple wire and an Analog Devices AD594 Monolithic Thermocouple Amplifier. I put a home-brewed garage thermocouple together for you using a length of Type J thermocouple wire in Photo 5.

The AD594 is really an instrumentation amplifier that is pretrimmed to interface a Type J thermocouple with a microcontroller's analog-to-digital converter (ADC). The AD594 produces an output voltage of 10 mV/°C directly from a thermocouple input signal. I've assembled an AD594 design in Schematic 4. As you can see in this schematic, all of the rocket science is contained within the AD594. All we have to do is connect the thermocouple to the AD594 input pins and read the temperature voltages from the AD594 with a PIC's ADC module.

The AD594 hardware I've presented in Schematic 4 can only read positive temperatures as I have used a single-rail +5-volt power supply. If your application needs to read negative temperatures, you'll have to provide a  $\pm$  dual-rail power supply for the AD594.

Believe it or not, the code to read the AD594 temperature data is just as simple as the hardware. Let's

## LISTING 1

```

//*****
//*      CONFIGURE A2D AND COMPARATORS
//*****
ADCON0 = 0b00000000;    //select channel AD0
ADCON1 = 0b00001110;    //RA0 = ADC input
ADCON2 = 0b10111111;    //clocking RC osc - max
                        //acq time allowable
ADON = 1;                //turn on ADC module
CMCON = 0x07;            //comparators OFF

```

use the PIC18F2685's AN0 input to read the AD594 output (see Listing 1).

Remember that we must also use the PIC's TRIS function to declare RA0 (AN0) as an input. In this case, let's just make all of the PORTA I/O pins inputs:

```
TRISA = 0b11111111;
```

## LISTING 2

```

//*****
//*      GET AD594 TEMPERATURE READING
//*****
#define make16(varhigh,varlow) \
(((unsigned int)varhigh & 0xFF)* 0x100) + \
((unsigned int)varlow & 0x00FF)

void get_temp(void)
{
    char x;
    unsigned int sum;

    sum = 0;
    for(x=0;x<20;++x)
        ADCON0 = 0b00000000;
    GODONE = 1;
    while(GODONE);
    sum += make16(ADRESH,ADRESL);
    temp_in_C = sum / 40;
}

```

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The PIC18F2685's ADC module is capable of resolving 10 bits of resolution. That is equivalent to 1024 steps

including zero. The PIC18F2685's ADC is referenced to the supply voltage according to the cleared bits in the upper nibble of the ADCON1 register value. So, that means every step of the PIC18F2685's ADC will represent approximately 0.005 volts. That means that 1°C is equal to two ADC steps. So, to get an absolute temperature result we need only to read the ADC and divide by two. In the code that follows, I read the AD594's output 20 times, take the average of the 20 readings, and divide the average by two (see Listing 2).

Nothing to it. Now that you know how to make an AD594 work for you, I'll show you one that is ready for action in Photo 5.

### LISTING 3

```
dataLen = 4; //length of CAN message
id = brd_display_temp_id; //sender's CAN ID
data[0] = addr_ad594; //destination CAN ID
//the CAN message contains this data:
data[1] = temp_in_C;
data[2] = make8(temp_in_C,1); // high byte
data[3] = make8(temp_in_C,0); //low byte
while(!ECANSendMessage(id, data, dataLen, ECAN_TX_STD_FRAME));
```

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## CAN YOU DO THIS?

Yep. You're trained. The next time you tackle what seems to be a difficult embedded project, just kick back and think of the I/O basics you need to accomplish each individual task. Once you've worked out the fundamentals, merge all of the solutions together to complete the system's mission.

I'll leave you with something to consider. How would you send the AD594 data to another PIC-based computing node? Listing 3 shows how I did it.

Yes you CAN! Put another notch in your soldering iron. **NV**

## SOURCES

- **Microchip**  
([www.microchip.com](http://www.microchip.com)):  
PIC18F2685
- **Analog Devices**  
([www.analogdevices.com](http://www.analogdevices.com)):  
AD594
- **Allegro MicroSystems**  
([www.allegromicro.com](http://www.allegromicro.com)):  
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- **Zetex Semiconductors**  
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- Fred Eady can be reached via email at [fred@edtp.com](mailto:fred@edtp.com).

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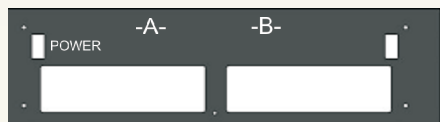


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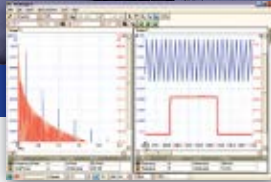
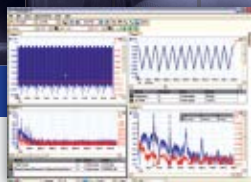
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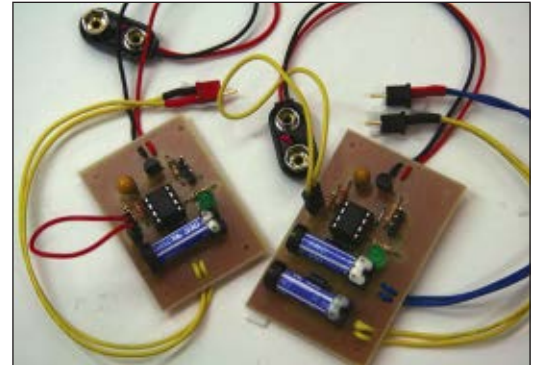
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■ BY L. PAUL VERHAGE

# NEAR SPACE APPLICATIONS USING THE PICAXE MICROCONTROLLER: Part 2

**THE PICAXE-08 IS A GREAT MICROCONTROLLER for small applications that don't require a lot of I/O pins or memory. This month, we'll look at two more small near space applications that are perfect for the PICAXE-08 and PICAXE-08M. The first is a programmable camera timer that replaces the standard 555 timer circuit used in most BalloonSats. The second is a cut down device that ensures the timely termination of a near space mission and the separation of the balloon's fragments. So, let's see what we can do with a microcontroller that can be purchased with pocket change.**



■ FIGURE 1. Two camera timers ready for a mission. Photo by Heidi Bailey, Dennis Technical Center, Boise, ID.

**T**raditionally, BalloonSats have used a 555 driven relay circuit to

operate their onboard cameras. The 555 circuit that appears to be the norm is a 12 volt intervalometer kit designed for high current applications. The result is a circuit that, in my opinion, is a bit large and clunky for BalloonSats.

Take a look at Figure 1. The two camera timers described in this month's column are replacements for this timer. They are lower in power and programmable. Since their interval is programmed, there's no need to adjust a

trimmer to get the proper timing like there is with a 555 timer based intervalometer. In fact, it's possible to program the timer to record photographs at changing intervals during a mission, which is something the older 555 based intervalometer kit is unable to do.

Another feature is that the timers have a commit pin. Until the shorting block is removed from the commit pins, the timer waits to begin taking pictures. This means fewer wasted pictures of the ground before the mission starts and more of the ground and sky during the actual mission.

The first timer is a single channel version that operates the shutter of the camera attached to it. The second timer is a two channel version that first powers up its camera, triggers the camera to take a photograph, then shuts down the

## CAMERA TIMER PARTS LIST AND FUNCTION

- LM2940T-5 (voltage regulator or power supply for PICAXE and relay)
- 22  $\mu$ F electrolytic capacitor (filtering for LM2940)
- 10K resistor (current limiter for programming header)
- 22K resistor (pull-down for programming header)
- 1K resistor (pull-up for commit pin)
- 1K resistor (current limiter for indicator LED)
- LED (indicator)
- 1N4001 diode (protection against back current)
- 5V reed relay (electrically operated switch)
- PICAXE-08 (programmable microcontroller)

*The two channel version of the camera timer requires a second relay and diode.*

*The reed relay is RadioShack part number 275-232.*

**NOTE:** All PCB patterns and files are available on the *Nuts & Volts* website at [www.nutsvolts.com](http://www.nutsvolts.com).



■ **FIGURE 2.** The schematic of the single channel camera timer. The two channel version has a second relay and diode connected to PICAXE-08 pin 4, or pin 3 on the IC.

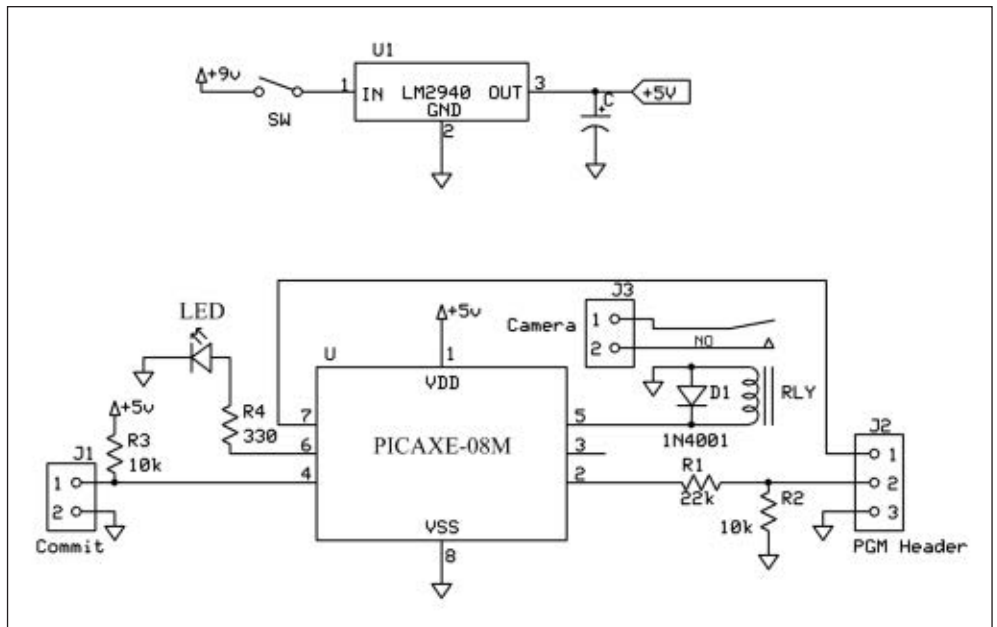
camera. The two channel version has full control over a camera and is best for cameras with power-save features that may shut it down during a mission. However, the two channel camera timer is not limited to operating a single camera. It could operate two separate cameras inside a BalloonSat or a single camera along with a second device that a relay can operate.

## THEORY OF OPERATION

Upon powering up, the PICAXE blinks its indicator LED (connected to pin 1) five times showing its readiness, then goes into a wait loop until the shorting block is pulled off the commit pin. The commit pin pulls pin 3 to +5V and the shorting block shorts it to ground. After detecting the removal of the shorting block (that is, when pin 3 goes high), the PICAXE signals its detection of the removal by blinking the indicator LED five more times. Then, the PICAXE enters an infinite loop where it energizes the relay by setting pin 2 high and turning on the indicator LED by setting pin 1 high. The LED is a troubleshooting tool that indicates when the PICAXE is triggering the relay to take a picture.

After a one second pause, the PICAXE sets pin 1 and pin 2 low to open the relay and shut off the indicator LED. When the PICAXE turns off the relay, the magnetic field contained within the relay's coil collapses and creates a potentially damaging reverse current through pin 2. To protect the PICAXE from damage, the 1N4001 diode shorts the relay's coil to reverse current. After a pause, the PICAXE again sets pin 1 and pin 2 high to then take the next photograph.

The two channel camera timer



operates the same way, except that its two relays are fired in sequence. The first relay attaches to the camera's power switch, allowing the PICAXE to power up the camera. After a short pause, the second relay (which is connected to the camera's shutter switch) fires to take a picture. After the camera has time to save the image to memory, the first relay is fired once more to shut down the camera.

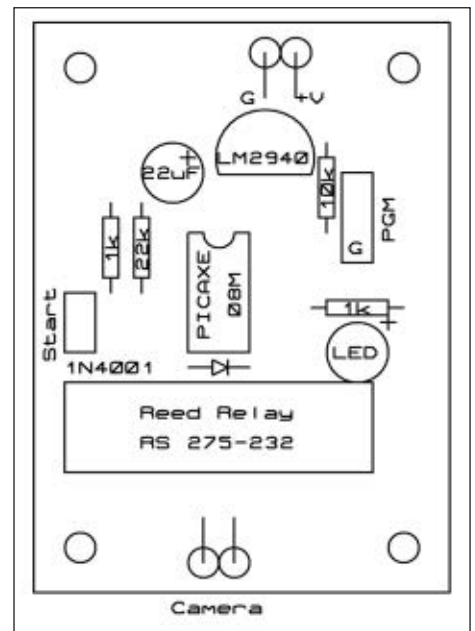
## BUILDING THE ONE AND TWO CHANNEL CAMERA TIMER

Begin assembling the timer by soldering the lowest lying components (the resistors and diodes) first. Solder an eight pin IC socket to the PCB rather than the PICAXE to protect it from the heat of soldering. I recommend using snappable headers for the programming header and commit pin (it's cheaper to purchase a long row of headers and snap them off as needed). Watch the orientation of the LM2940 voltage regulator and the diode(s). If the diode is soldered backwards, it will short out every time the PICAXE fires the relay.

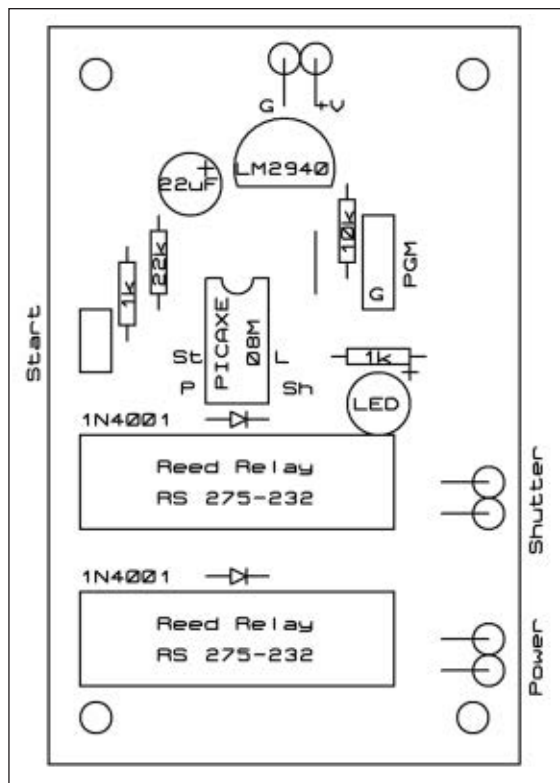
The large holes at the top and bottom (and sides in the two channel

version) are strain relief holes for the timer. Wires connecting the timer to the camera and battery pack pass through the strain relief holes to prevent normal use breaking the soldered wires off of the PCB. The battery holder for the timer can either be a nine volt battery snap or a four cell AAA holder.

The commit shorting block is a short loop of wire terminated with small crimps and mounted inside a plastic housing. A cord tied to the wire loop of the shorting block exits the BalloonSat airframe and is attached to a brightly colored tag.



■ **FIGURE 3.** One channel camera timer.



■ FIGURE 4. Two channel camera timer.

these timers only work for cameras with electrical switches. Fortunately, this means they'll work for most modern cameras.

You'll need to open the body of the camera to attach the timer. **Warning!!** Part of the camera's flash circuit is a high-voltage electrolytic capacitor that's capable of delivering a nasty shock. *Under no circumstances touch this capacitor*, as it can hold a hefty charge long after the batteries have been removed. Apply electrician's tape over the capacitor's exposed wires if you're concerned that you might accidentally touch them (would anybody intentionally touch them?).

Open the camera only far enough to expose the solder pads of the shutter switch. After opening the camera, it's a good idea to test the camera once again for damage by loading batteries and pressing its shutter switch. Remove the batteries after testing and set a multimeter to measure resistance or continuity. Using the meter, identify which of the two of the switch's pads connect to each other when the button is pressed. If the multimeter leads are touching the correct two pins, the multimeter will indicate zero ohms of resistance when the switch is pressed.

Rather than try to remove the shutter switch from the camera, just solder thin gauge wires to the two pads and then run them out of the camera case. It would be a good idea to run the wires through a hole or pair of holes in the camera case where they can be tied off for strain relief. The free ends of the wires are then soldered to the timer.

Now, here's a complicating factor. Some cameras

have three pins on the shutter switch that are connected together when the shutter switch is pressed. Typically, the third pin triggers the camera to focus (so you should only see this happen with an autofocus or AF camera). You can determine if the camera has a focus pin in its shutter switch by noting if a third pin shorts when the button is only half pressed. However, to do this, you first have to locate the shutter switch pin that connects to ground.

The switch's ground pin is the pin that the autofocus and shutter pins connect to when the shutter switch is pressed. After you identify the focus and shutter pins in the switch, connect both to one side of the relay and the ground pin to the other side. Shorting the focus and shutter pins together like this causes the camera to focus and take a picture together when the relay is fired.

A possible alternative is to solder a wire between the shutter switch focus pin to the ground pin. This keeps the camera constantly focusing itself and should be okay as long as it doesn't drain the battery during a typical two to three hour flight.

Connecting the two channel timer to a camera is done the same way except the second relay connects to the camera's power switch. Follow the above procedures to locate the correct pins to connect to the relay.

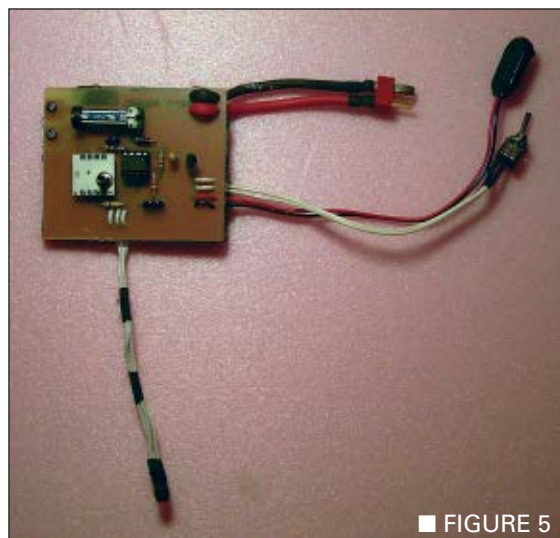
## FINISHING THE PICAXE CAMERA TIMER

Now download the PICAXE program and test the circuit. At power up, the LED indicator will blink and the timer will wait for the removal of the shorting block. Once the block is removed, the timer will begin taking pictures and lighting its indicator LED. If the timer checks out, cover the back of the PCB with a piece of foam core and hot glue to protect the traces on the underside from shorting out. The PICAXE BASIC code for the single channel camera timer is available on the *Nuts & Volts* website at [www.nutsvolts.com](http://www.nutsvolts.com).

The tag is marked with text (like Remove Before Launch) to remind the launch crew to pull the shorting block off the commit pins before the balloon lifts off.

## CONNECTING A CAMERA TO THE PICAXE CAMERA TIMER

The relay in the timer replaces a camera's shutter (and power switch in the two channel version). Therefore,



■ FIGURE 5



## THE PICAXE TERMINATOR

This month's second PICAXE project is a terminator. While this terminator is not a famous movie character, it does contain a PICAXE (PICAXE Inside?). The PICAXE Terminator ensures that a near space mission ends on time by cutting away the balloon. Occasionally, near space missions fail when the weather balloon becomes neutrally buoyant. When that happens, the balloon stops rising and the near spacecraft remains at a fixed altitude until the onboard battery dies. Once power is lost, the near spacecraft stops transmitting its position and becomes lost. The loss of a near spacecraft can be expensive considering that onboard it is a GPS receiver, amateur radio, and a radio modem called a TNC.

Normally, if the balloon's lift is at least three pounds greater than the weight of its payload, a neutrally buoyant condition won't occur. However, if the balloon develops a slow leak or if the balloon's lift is set low in an effort to reach the maximum

possible altitude, the risk of a neutrally buoyant condition increases.

The PICAXE Terminator makes sure missions like these still end in a timely fashion. Even if the balloon bursts properly, cutting away the balloon fragments makes the rest of the descent less chaotic for the near spacecraft.

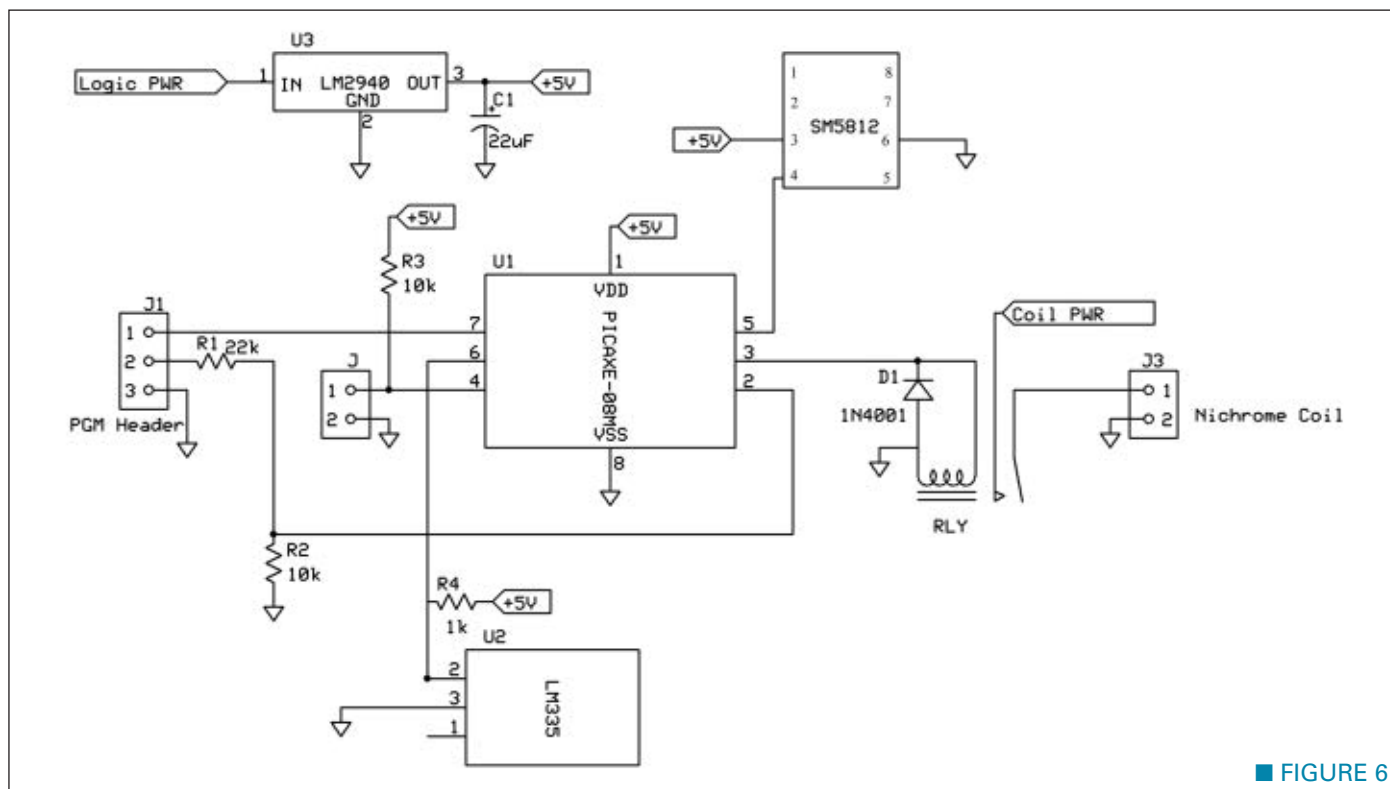
The PICAXE Terminator monitors two flight conditions and acts as a mission timer. The two environmental conditions monitored are the air pressure and air temperature. On a near space mission, the air pressure decreases until the balloon bursts. The air temperature initially decreases as the balloon climbs through the troposphere and then begins increasing once the balloon enters the stratosphere. But then at balloon burst, the air temperature drops rapidly. Code in the PICAXE waits for either the air temperature to drop after it rose earlier in the

## TERMINATOR PARTS LIST AND FUNCTION

- 1K resistor (voltage divider resistor for the LM335)
- 10K resistors (current limiting resistor for PICAXE programmer and pull-up resistor)
- 22K resistor (pull-down resistor for PICAXE programmer)
- 22  $\mu$ F electrolytic capacitor (voltage regulation)
- LM2940T-5 (voltage regulator)
- Toggle switch (power switch)
- 1N4001 (kick back suppressor diode)
- Reed relay (electrical switch)
- LM335 (temperature sensor)
- SM5812 (pressure sensor)
- PICAXE-08M (programmable microcontroller)
- Two Pin male header (commit switch)
- Three Pin male header (programmer header)

*The SM5812 is a Silicon Microstructures pressure sensor. A datasheet is available at [www.si-micro.com](http://www.si-micro.com). The part can be ordered from [www.servoflo.com](http://www.servoflo.com).*

flight, for the air pressure to begin increasing, or the air pressure to reach a minimum value coded into the program. When any of these events occur, it signals that the balloon has burst or has reached its



■ FIGURE 6

desired maximum pressure altitude. Otherwise, the PICAXE Terminator waits until the programmed maximum time has elapsed.

To cut away the balloon, the PICAXE fires the relay for 10 seconds. The current flowing through the relay heats the nichrome coil to a dull red, melting the line running through it. The line separates letting the near spacecraft drop and the balloon rise by itself. Without the weight of the near spacecraft holding it back, the balloon quickly ascends to an altitude where air pressure will burst the balloon. It's guaranteed to burst even if it was previously in a neutrally buoyant condition.

## THEORY OF OPERATION

The ADC in PICAXE pin 1 and pin 2 digitizes the voltages of the two sensors in the terminator. Pin 1 connects to the output of the LM335 temperature sensor. This sensor produces a voltage of 0.01 volts per degree Celsius. Theoretically, the sensor produces zero volts at absolute zero, or 0 kelvins and maxes out with five volts at 500 kelvins or

227 degrees Celsius (that's 440 degrees Fahrenheit).

PICAXE pin 2 connects to the output of the SM5812 (or its equivalent) pressure sensor. This sensor produces 0.5 volts in a vacuum, 4.5 volts at one atmosphere of pressure, and its output is linear with atmospheric pressure. PICAXE pin 3 connects to a pair of pins that are pulled up to five volts with a 10K resistor. While the shorting block is on the pair of pins, pin 3 is shorted to ground. pin 4 connects to the coil of a 5V reed relay. When set high, pin 4 energizes the relay's coil, switching six volts to the terminator's nichrome coil which gets hot and melts the load line between the balloon and parachute.

The programming header not only allows the program in the PICAXE to be updated, but also allows access to data stored in PICAXE memory. On each mission, the PICAXE records eight, one byte environmental records into memory. By reviewing these records, the terminator's program can be tweaked for better performance. Here's a table of conditions that the PICAXE-08M

stores and their memory locations:

Condition	Location
Air pressure at commit	0
Air temperature at commit	1
Time to tropopause	2
Air pressure at tropopause	3
Air temperature at tropopause	4
Time at cutdown	5
Air pressure at cutdown	6
Air temperature at cutdown	7

After powering up the terminator, the PICAXE waits in a program loop for pin 3 to go high (five volts). The transition to five volts takes place when the launch crew removes the Commit tag which is connected to a shorting block like the one described above for the camera timer.

After the tag is removed, the PICAXE first dumps the data in its first eight bytes of memory (use the PICAXE programmer's terminal feature to read them). Next, the current air pressure and temperature are recorded into memory. Since it takes a few minutes to finish raising the balloon before its release, the PICAXE goes into a short wait loop before it will begin monitoring the time, temperature, and pressure. Then, the PICAXE enters into a one minute loop where the time is incremented and the pressure and temperature are digitized and recorded as needed.

Air pressure decreases with increasing altitude, however, air temperature only decreases with increasing altitude until the balloon enters the stratosphere. Once in the stratosphere, the air temperature begins increasing with increasing altitude because of the ozone layer. When the air temperature begins increasing (which occurs between 40,000 and 50,000 feet), the PICAXE records the elapsed time, the air pressure, and air temperature as the time, pressure, and temperature of the tropopause — the boundary between the troposphere and stratosphere.

The one minute program loop continues until the maximum time is exceeded, the pressure begins to increase, the air pressure reaches its minimum value, or the air temperature begins dropping after the balloon has

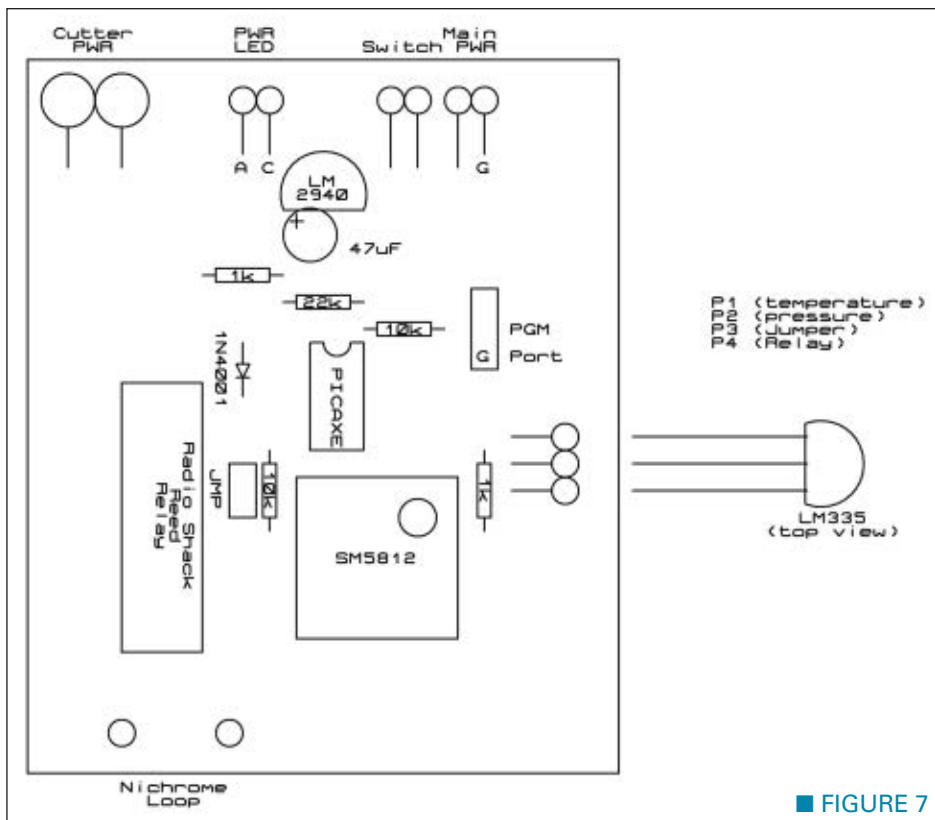


FIGURE 7



been detected entering the stratosphere. When it's time to cut the load line, the PICAXE records the final time, air temperature, and air pressure into memory. It then fires the relay for 10 seconds to melt the line before ending the program.

## BUILDING THE PICAXE TERMINATOR

Like the camera timers above, the first components soldered to the PICAXE Terminator PCB should be the lowest lying components (that is, the resistors and diode). Solder an eight pin socket to the PCB instead of the PICAXE to protect it from damage. Use snappable headers for the programming header and shorting pins. The components sensitive to orientation are the diode, voltage regulator, regulating capacitor, LM335, SM5812, and ultimately, the PICAXE. Be sure to double check their orientation before soldering them into place. Since the circuit is housed inside a Styrofoam box, the temperature sensor and power switch must be mounted to cables in order for them to reach the outside of the box.

The terminator's nichrome coil mounts to the two holes at the bottom left of the PCB with #2-56 hardware. Use a three inch length of thin gauge nichrome wire for the coil (my spool of nichrome wire is about 30 AWG). Wrap the nichrome wire around a 3/16 inch diameter dowel to form the coil (I use a jeweler's screwdriver). The ends are curled around the #2-56 bolts and firmly bolted to the PCB.

## CONNECTING THE PICAXE TERMINATOR TO THE NEAR SPACECRAFT

Since I've not had a chance to test the PICAXE Terminator in flight (only ground tests have been performed to date), I haven't finalized its mounting design. However, I envision mounting the terminator to a sheet of Sintra plastic or thin modeling plywood. This mounting plate will be large enough to hold the terminator PCB on one side and two batteries, the logic battery (9V transistor battery), and the nichrome heater battery (either a rechargeable or camera battery) on the back. The logic battery will be a lithium 9V battery and the nichrome coil battery will be either a 7.2V rechargeable lithium or a non-rechargeable 6V lithium camera battery.

Attached to the mounting plate and directly in line with the nichrome coil are two brass or aluminum tubes, with one above the PCB and the other below. The load line runs through these two tubes to align the load line with the nichrome wire coil. The tubes prevent the load line from pulling the coil out of shape or free of the PCB.

The bottom of the mounting plate attaches to the apex of the recovery parachute with a split ring that's also positioned in line with the nichrome coil. If the ring is not mounted directly underneath the nichrome coil, then the load line will twist up around the nichrome coil as the balloon rotates in relation to the parachute.

There are two things to note here. First, it's the

mounting plate that attaches to the parachute (via its split ring) and not the terminator PCB. Second, the load line from the balloon doesn't tie to the mounting plate. The load line from the balloon only passes through the terminator and its mounting plate. Since the load line ties directly to the parachute apex, the PICAXE Terminator and its mounting plate do not experience stress from the weight of the near spacecraft.

To protect the batteries and nichrome coil from the cold of near space, a two piece Styrofoam box (a front and back face) will cover the mounting plate. The front face has holes that the LM335 temperature sensor, power switch, and Commit tag pass through. The box is held closed around the mounting plate with rubber bands. Rubber bands tolerate the cold and ultraviolet of near space well while allowing the balloon crew to quickly and easily open and close the box before the balloon is launched.

To make it easier for the launch crew, pass the load line through the PICAXE Terminator the night before and tie it to the parachute apex. The code for the PICAXE Terminator is also available for downloading on the *Nuts & Volts* website.

Well, that's all for this month. Next time is a report on the Spaceward Game that my girlfriend Rachel and I attended. Until then,

*Onwards and Upwards,  
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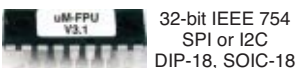
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## READER FEEDBACK

*Continued from page 8*

on my articles. Using LEDs for audio communications sounds like a neat thing to do. I would be curious to see the circuit Mr. Bennett used to do this, as I think this would be a great project for my students to attempt. I did experience some problems with the blue LEDs that I need to investigate later, so infrared, red, orange, yellow, and green should work as the LED photometers I wrote about in the column. Sometimes it amazes me with what we can do with a handful of parts from our junk box.

**Onwards and Upwards, Paul**

## REFERENCE TO QUALITY

I'm writing to congratulate you and Doug Malone for the excellent article, "Build a 0.01% Accurate Voltage Reference," which appeared in the Sep '07 issue of *Nuts & Volts*.

As a retired electrical engineer who did analog circuit design at companies such as Quantum and Western Digital, I can readily appreciate the superb design and clear description that Doug wrote for your magazine, plus attention to detail when laying out the board. This is evident in the stress relief cuts he made in the vicinity of the reference IC.

Not having any skills when it comes

to soldering surface mount parts, I ordered two PCBs from Doug with the reference IC installed. There was a small typo in the parts list, but an email to Doug brought a prompt reply with the right part number.

When the boards arrived and the additional parts were installed, I was very pleased to find that the output of the two reference supplies differed by only 200 microvolts. A truly remarkable achievement considering the cost involved. Back when I was doing analog circuit design, it would have cost at least 20 times as much and required a temperature controlled oven to obtain similar results.

**Phil Kenny**



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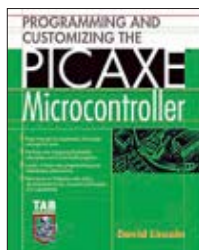


## ELECTRONICS

### Programming and Customizing the PICAXE Microcontroller

by David Lincoln

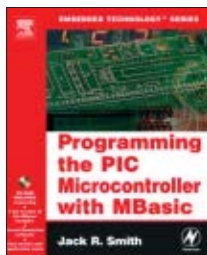
Here's everything you need to harness the power of PICAXE, the inexpensive yet versatile chip that's taken the electronics community by storm. This beginner-friendly guide from IT pro and PICAXE expert David Lincoln shows you just what Revolution Education's PICAXE can do — and helps you make it do it! Packed with ready-to-build projects for all the flavors of PICAXE. **\$39.95**



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by Jack Smith

No microcontroller is of any use without software to make it perform useful functions. This comprehensive reference focuses on designing with Microchip's mid-range PIC line using MBASIC, a powerful but easy to learn programming language. It illustrates MBASIC's abilities through a series of design examples, beginning with simple PIC-based projects and proceeding through more advanced designs. **\$62.95\***



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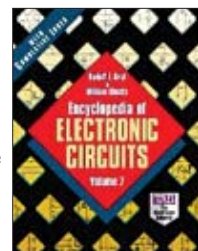
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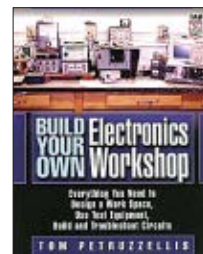


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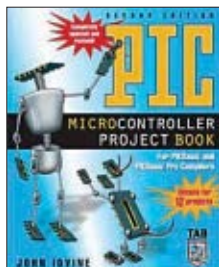
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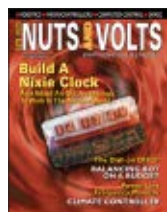
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As seen in the November 2007 issue



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As seen in the October 2006 issue



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**For more information, please check out your October 2006 issue or go to our website @ [www.nutsvolts.com](http://www.nutsvolts.com)**

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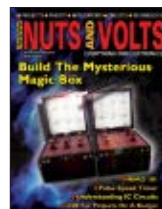
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our April issue.

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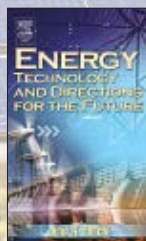


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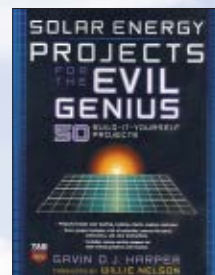
*Publish Date: January 26, 2004*

This book is a survey of energy sources that will be available for use in the 21st century energy mix. You will learn about the history and science of several energy sources, as well as the technology and social significance of energy. The book includes geothermal energy, fossil fuels, solar energy, nuclear energy, alternate energy and society, energy and the environment, sustainable development, the hydrogen economy, and energy forecasting. **72.95\***



### Solar Energy Projects for the Evil Genius by Gavin D. J. Harper

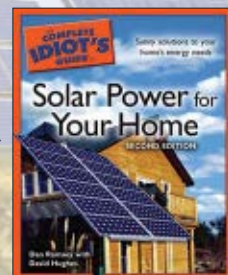
Let the sun shine on your evil side — and have a wicked amount of fun on your way to becoming a solar energy master! In *Solar Energy Projects for the Evil Genius*, high-tech guru Gavin Harper gives you everything you need to build more than 50 thrilling solar energy projects. You'll find complete, easy-to-follow plans, with clear diagrams and schematics, so you know exactly what's involved before you begin. **\$24.95**



### The Complete Idiot's Guide to Solar Power for Your Home by Dan Ramsey / David Hughes

*Publish Date: May 2007*

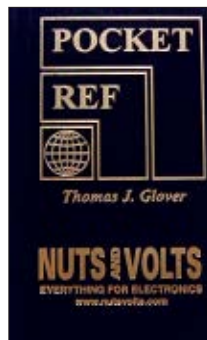
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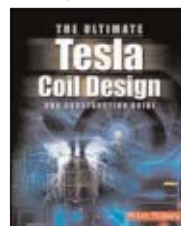


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### The ULTIMATE Tesla Coil Design and Construction Guide by Mitch Tilbury

*Publish Date: September 21, 2007*

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# TECH



# FORUM

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All questions and answers should be sent by email to [forum@nutsvolts.com](mailto:forum@nutsvolts.com) All *diagrams should be computer generated and sent with your submission as an attachment.*

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- ④ Other Similar Topics

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■ Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

## >>> QUESTIONS

Anyone know a rule of thumb for determining how much energy you can pump into an LED without destroying it? I've seen many specs on maximum voltage, current, and duty cycle. However, I'm trying to determine how much current you can actually pump into one in a short duration pulse (around one microsecond) without damaging the LED junction, and at what maximum repetition rate. I've heard of strobe applications where 10X the maximum absolute current could be pulsed without destroying the LED. But what is the limit and how do you determine it from the specs?

#1081

**Tom Campbell**  
Austin, TX

Does anyone know of a circuit that can produce pulses at a constant (but adjustable) duty cycle (around 3% or less) from 20 Hz to 20 kHz? I have seen many designs that can vary duty cycle or frequency, but not both without one affecting the other. This is for a strobe application.

#1082

**Tom Campbell**  
Austin, TX

I am working on a bingo flash board that will be shipped to Honduras. It is the big board that everyone watches after the bingo numbers have

been called. It has 75 lighted 2" x 2" segments that can be individually lit as the numbers are called. I have the bingo machine controller but it is old and unfixable. What I need to do is come up with a way to control the lighted board. I am open to suggestions. I thought about using a PIC and a digital input pad to input the number. You could even use relays and 75 switches but having that many wires may be a bit much.

#1083

**Charlie Brown**

How can I extract music files (usually .wav or .mp3) embedded in Microsoft Power Point files?

#1084

**Steve Buu**

Is there a way to export stock market data from the Internet (PC) through USB or RS-232, to be displayed on a homemade stock sticker?

#1085

**Steve Buu**

Where is the current cursor position from the mouse stored in Windows (PC) and how can it be accessed? I want to externally control the cursor in addition to the mouse.

#1086

**Steve Buu**

Brushless motors are more powerful and efficient than the old brush motors but are much more sensitive to overload/overcurrent. For radio control and robot competition, I

want to get as much power as possible without burning out the motor. In this application, space is limited and there is minimal air flow for cooling.

Is there a way to limit the maximum current allowed to the motor, even if stalled (a virtual short circuit), while still allowing throttle control up to that limit? The smallest motors run 10 amps continuous at 7 to 12 volts and the big ones over 40 amps at 30 to 50 volts.

#1087

**Dan Schwartz**  
Northbrook, IL

buttons which she can't see or remember which ones to press.

*The functions she needs are TV off/on, volume and channel up/down. I want to build a simple remote with giant buttons that are perceptually different for each of these two-dimensional control functions in hopes that she will intuitively feel the difference.*

**#1** I think I have found the perfect remote for Stan's mother to use. The TV remote that he described in his question reminded me of one that we

had purchased for our kids to use. It is called the "weemote." When I visited the manufacturer's website to provide Stan with the information, I found that they now make an adult version called the "weemote Sr. TV remote for adults." More information can be found at [www.weemote.com](http://www.weemote.com).

**Greg Cloutier**  
South Windsor, CT

**#2** If you go to [www.tauntek.com](http://www.tauntek.com), check out two chips: one called IRMimic and another called IRMimic2.

## >>> ANSWERS

### [#10074 - October 2007]

*I have been using the serial port of my PC and languages such as assembly, C++, Java, and VB to communicate with custom designed circuits. Nowadays, all PCs have replaced the serial port with multiple USB ports. I want to migrate my applications but have found working with USB rather difficult. Could someone please suggest a way to send/receive a simple 1-0 digital signal using any programming language (preferably Java)?*

I'm assuming that your current Java implementation uses the javax.comm package to communicate with the serial port. If this is the case, by far the easiest way to adapt your projects for use with computers which have no serial port is to use a USB-to-serial converter. These are available from many sources on the web for under \$20 and are very easy to use. See <http://sewelldirect.com/usbtoserial.asp> for a specific example. If you'd rather have something that can be built into your project, take a look at [www.pololu.com/products/pololu/0391/](http://www.pololu.com/products/pololu/0391/)

**Tom Dimock**  
Ithaca, NY

### [#11072 - November 2007]

*My mother has Alzheimer's and is unable to operate her television anymore. We had a very simple remote with about six large buttons which she could use. That TV broke and our new 37 inch LCD is a good size for her, but the remote has about 40 tiny*

### [#10075 - October 2007]

*I have an irrigation system with a six zone controller. It has only four wires plus a ground going to it and the valve box. It would be impossible to run new or additional wire as the wiring goes under a concrete floor.*

*Four zones are being used. I recently added a fifth battery-operated zone, but it's a problem as the batteries tend to wear out. I want to use the controller for timing zone five and would appreciate a circuit that could do this.*

Let's take a simple, low-tech approach to the problem. The zone outputs are all AC. By using only the positive half-cycles from one zone and only the negative half-cycles of the next, we can have two zones share one control wire. We will use the common ground as one conductor (which will remain grounded), and use one conductor for unswitched 28 VAC. This leaves three conductors for control, which allows you to use all six zones.

Referring to the diagram, here's

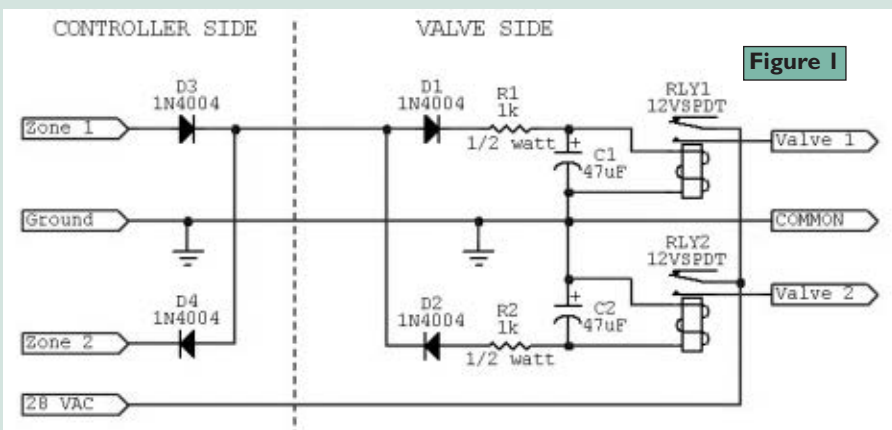
how it works. When zone 1 is active, 28 VAC is rectified by D3 so only positive half-cycles are sent down the control wire. Out at the valve end, D1 allows the positive half-cycles to charge C1 through R1. C1 keeps the 12 volt DC relay from chattering due to half-cycles being applied to it. R1 drops the voltage down to approximately 12 volts. Since D2 is reverse-biased, RLY2 is not pulled in. The same thing happens when zone 2 is active, only this time we are sending negative half-cycles down the control wire to pull in RLY2.

The drawing shows the circuit for two zones. By duplicating the circuit two more times, you will have six zones available. All circuits share the same ground and 28 VAC conductors.

The typical RadioShack part numbers are:

C1, C2:	272-1015
D1 - D4:	276-1003
R1, R2:	271-1118
RLY1, RLY2:	275-248

**Rick Curl**  
Pinson, AL



**Figure 1**



These chips can memorize commands from your existing remote, for playing back under control of your own switches. With IRMimic2, you can record several commands and then play them back in sequence as a macro, all in response to one button press.

**Bob Grieb**  
Medford, NJ

**[#11073 - November 2007]**

*In the past several years, it has become harder and takes greater pressure to make contact with most of the rubberized keys on our TV remote.*

*Inside, I've noticed a slimy film covering the circuit board and keys. I've cleaned everything with contact cleaner. It worked for several months, then, the same old problem re-appeared.*

**#1** I also have seen the problem with remote controls and some two-way radios that use pressure type switches. The carbon impregnated rubber either becomes contaminated or wears away over time.

A solution that I have found is to buy some adhesive backed foil. Craft stores and home centers carry metal tapes that should work. I have a few rolls of tape that I got from RadioShack years ago that were used on audio tapes.

Take either a handheld hole punch or a hobby knife and cut the foil to fit over the carbon part of the rubber buttons, where they depress against the PC board inside of the remote control. Carefully place the adhesive foil over the old rubber, trimming it to fit neatly and reassemble the remote.

Whenever you press one of the buttons, the foil will make contact with the PC board instead of the less or non-conducting carbon coating. The foil will make good, long lasting contacts that should be much less prone to contamination or wear.

**E. Kirk Ellis, KI4RK**  
Pikeville, NC

**#2** I have successfully cleaned dozens of remote controls using the following method. This is a long-term solution if the carbon pads

are not worn out.

Carefully pry apart the remote control; some may have screws holding it together. Place the pad in a tall microwave safe drinking glass. Cover the pad with water to one inch above the pad. Add one teaspoon of table salt. Place in a microwave oven and microwave on high power for three or four minutes. Remove it from the oven and add a squirt of liquid dishwashing soap. Stir well, remove the pad, and carefully scrub it with a toothbrush. Also, clean the remote control top cover, inside and out. Rinse well and allow to dry. To clean the circuit board, I use Rawn contact/degreaser part #1118 (available from MCM; order #20-2005). Use a paper towel saturated with this and wipe the board and keypad.

You may also use denatured alcohol, but be careful not to get any on the plastic case.

**Norman Nollett**  
Valentine, NE

**#3** The slimy build-up on the PC board can be all or just part of the

problem. In our shop, we clean the rubber buttons with dish soap and warm water. Clean the board contacts with 90% alcohol. If that works well and excess pressure isn't needed to operate, return it to service and consider some form of plastic bag, wrap, or other protection to keep it from the drink spills that no one will ever admit to. If the excess pressure or no operation still persists, apply conductive coating to the bottom of the rubber key pads. (Caig Caikote 44 #K-CK44-G, MCM #200-315 or Chemtronics Rubber Keypad Repair Kit #CW2605; MCM #20-3890.)

**Ivan Strong**  
Des Moines, IA

**#4** Make sure the contact cleaner you're using is of the fast dry, non-residue type (non-lubricating). "The slimy film" may be left over from the contact cleaner and will attract dirt to the contact pads. Isopropanol alcohol can also be used to clean these type of contacts.

**Bob Lindstrom**  
Broomfield, CO

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# IN THE SPOTLIGHT



## *An Interview with Gary Johnston Managing Director, Jaycar Electronics*

by Marvin Mallon

**T**his month's spotlight is on Jaycar Electronics, a mail order business offering a wide variety of electronic equipment with company stores located throughout Australia and New Zealand. They also maintain a manufacturer's rep/distributor business for semiconductors and other electronic components in those countries and additionally in Singapore, India, and elsewhere. A Mr. Jock Carr founded the company in 1950. Mr. Carr died in 1962 and Gary Johnston purchased the firm which had all but ceased to function in 1980. He revived the business to the point where it presently has approximately 650 staff members and over 50 company owned stores (not franchises).

Gary is the sole owner of the business. He began operating Jaycar when he was 30 and is now 57 years old. Prior to owning and operating Jaycar, he worked for a company called Dick Smith Electronics. They are an Australian firm that tried to enter into the American marketplace in the early 1980's, but they did not succeed. He left that organization before that occurred.

The main office and warehouse of Jaycar occupies 70,000 square feet. They are moving later this year to a 200,000 square foot facility.

When interviewed for this column recently, he replied to our questions in this manner:

**Marvin:** Please describe the nature of your business and how it operates.

**Gary:** As a business, the closest thing in United States terms you could compare us to is a hybrid of RadioShack and Jameco. We also do a large range of do-it-yourself

kits so we are a bit like Ramsey, as well. We do not sell brand-name products at all. We generally either make kits up ourselves or source goods from overseas suppliers; generally Asia.

**M:** How many different products do you offer, either at your company stores or on the Internet?

**G:** On that subject, we generally release about 1,000 new products every year on a range of 8,000. We discontinue about 500 products a year so our range is growing overall. Naturally, we would like a smaller number of products to manage, but it just does not seem to work out that way. As we indicate on our website, we do not skimp on quality with our kits. We supply 1% metal film resistors in lieu of 5% carbon ones. We use high quality MKT style plastic capacitors and IC sockets, where appropriate. Our kit production department is audited under the ISO9001:2000 Quality System, an International benchmark. Jaycar sells kits all over the world these days. We cannot afford to let someone down whether they are in Birmingham, England or Birmingham, Alabama. The kit that a customer receives in Melbourne, Florida, is the same as the one delivered to a customer in Melbourne, Australia. We source projects from all over the world.

**M:** How much business do you do annually?

**G:** We are not a publicly traded company and we tend to keep financial details to ourselves, but in US dollars, our ballpark retail turnover is about \$70 million. That's pretty big by Australian standards, but nothing

compared to RadioShack! We require a minimum order of \$15 USD for our American customers. Other minimums apply for other countries. Shipping charges are a function of order value, distance, and method of shipping.

**M:** Care to comment on any problems you have selling your products in an American market?

**G:** We have been producing a US dollar version of our catalog for some years now. While we have had some success marketing to enthusiasts in the USA, I think that Americans have a perception problem with "down under." I feel that many Americans just don't see Australia as a source of technical products. Heck, we make half the world's heart pacemakers down here, for example. We also make about 25 percent of the world's slot machines — and the really electronic ones at that.

**M:** Finally, how can our readers get information about your product line and place orders?

**G:** We have a 400+ page US catalog that is free to any US or Canadian customer. They only have to contact us at **www.jaycar.com.au**. We have been around for over 50 years, and welcome any customer who holidays down under to pay us a visit. There is a reason why we are so big down here and we would love to prove our worth to US enthusiasts. **NV**

### JAYCAR ELECTRONICS

Tel: 800-784-0263

Email:

[techstore@jaycarelectronics.com](mailto:techstore@jaycarelectronics.com)

Web: [www.jaycar.com.au](http://www.jaycar.com.au)





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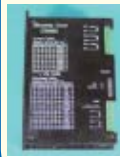
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The CSI-6028 is a small yet powerful rework system. The Sirocco style fan induces seamless airflow thru the heating element providing convection style heating, and this non-pressurized air stream works perfectly for reworking highly sensitive IC packages such as BGA, QSP, SOP and plastic based SMD devices.



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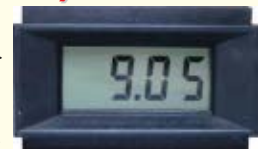
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Each module can send and receive serial data and 2 modules are required for communication. A simple example of sending data from a BASIC Stamp 2 microcontroller is:

```
SEROUT 0, 84, ["Hello World"]
```

*Features of the 912 MHz RF Transceiver:*

- 800 foot range
- 9600 bps serial (9600, N, 8, 1)
- 16-bit CRC error checking
- FIFO buffer
- +3V to +5V operation
- Built-In antenna



*Note: Each module can send and receive serial data and two modules are required for communication.*

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